NOAA TECHNICAL MEMORANDUM NWS CR-79

DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

ON THE MIDWESTERN DIURNAL CONVERGENCE ZONE ON THE WEST SIDE OF THE WARM SEASON BERMUDA HIGH

Bartlett C. Hagemeyer
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U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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1. INTRODUCTION

In a study of local air mass showers over the Upper Current River Valley (UCRV) of the Missouri Ozarks during the 1984 warm season (Hagemeyer, 1985) it was discovered that on three days of the study the showers over the UCRV were actually part of an organized synoptic scale zone of non-frontal convection that extended from the Ozark Mountain Region to northern Indiana (Fig. 1). Associated squall line development was observed over northern Indiana and central Illinois on these three days, as was scattered shower and thunderstorm development over the Ozarks. On two of the squall line days severe weather occurred over northern Indiana. The general synoptic conditions on all three days of this organized convection were quite similar, being characterized by the blocking Bermuda High over the southeastern United States, a quasi-stationary front or trough over the central and northern Plains, and a warm or quasi-stationary front over the Great Lakes Region (Figs. 2a-e). Strong to severe thunderstorms were associated with the frontal zones, but it must be stressed that the thunderstorm development considered in this paper is neither associated with frontal boundaries or with pre-frontal travelling squall lines. Instead, it is believed that in each of the cases presented here the thunderstorm development resulted from an anticyclonically curving low-level jet (LLJ) on the western fringe of the Bermuda High which caused a low-level convergence zone during peak afternoon heating. This convergence zone will be called the Midwestern Diurnal Convergence Zone (MDCZ). The LLJ associated with the MCDZ is not the traditional LLJ stream associated with severe weather outbreaks or nocturnal thunderstorms. Instead it could almost be called a summer "ground jet" since maximum winds were observed between 300 m and 1000 m AGL. This type of LLJ is often associated with a unique summer barotropic atmosphere, and to my knowledge has not been specifically identified as a thunderstorm producer.

Case studies of the MDCZ will be presented and the role of the LLJ will be discussed qualitatively. Finally, a means of forecasting the LLJ position and its associated thunderstorms will be presented.

2. THE MIDWESTERN DIURNAL CONVERGENCE ZONE

The general synoptic setting that leads to favorable conditions for the development of the MDCZ is basically the same as that mentioned by

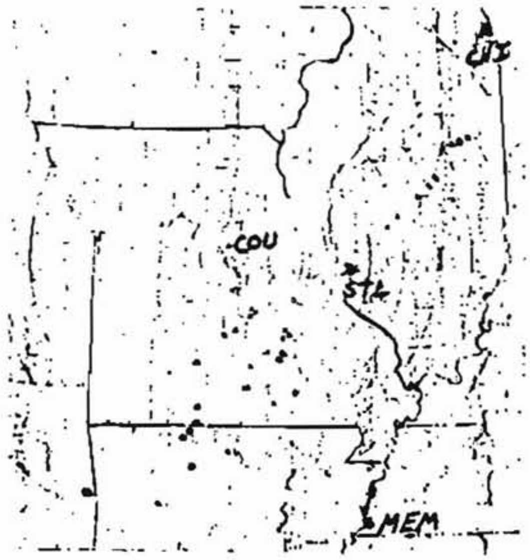


Fig. 1. Composite of the first echoes recorded on the radars of Columbia, MO, Monett, MO and St. Louis, MO on 12 June 1984, 17 June 1984 and 10 July 1984.

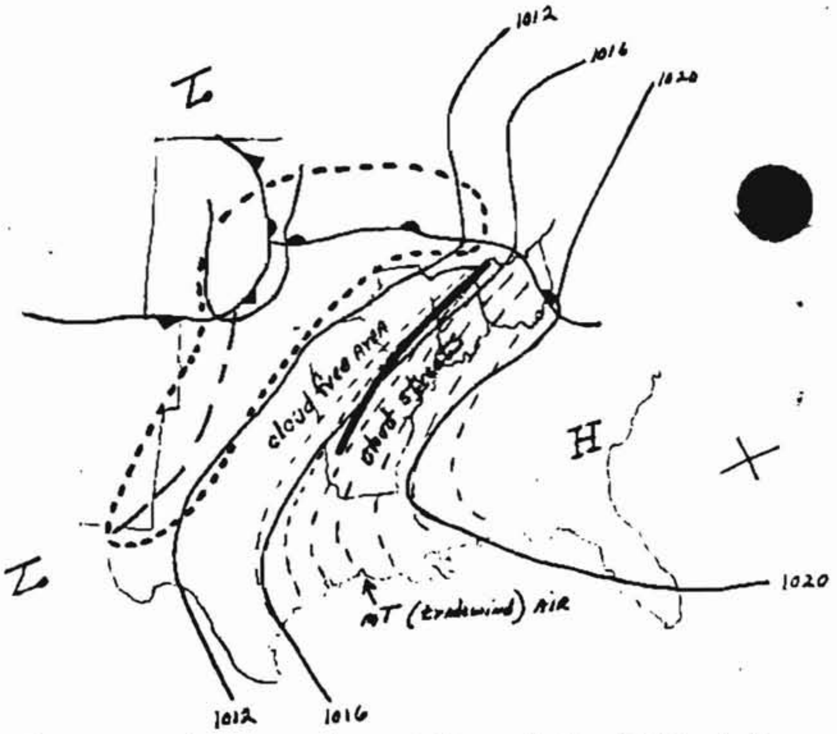


Fig. 2a. The synoptic setting of the MDCZ at the surface. The bold line is the MDCZ and the heavy dashed line encloses the area of frontal convection. The pre-MDCZ environment is characterized by widespread cloud streets and tropical low level moisture. (Map and 12 GMT isobars and fronts adapted from Daily Weather Maps.)

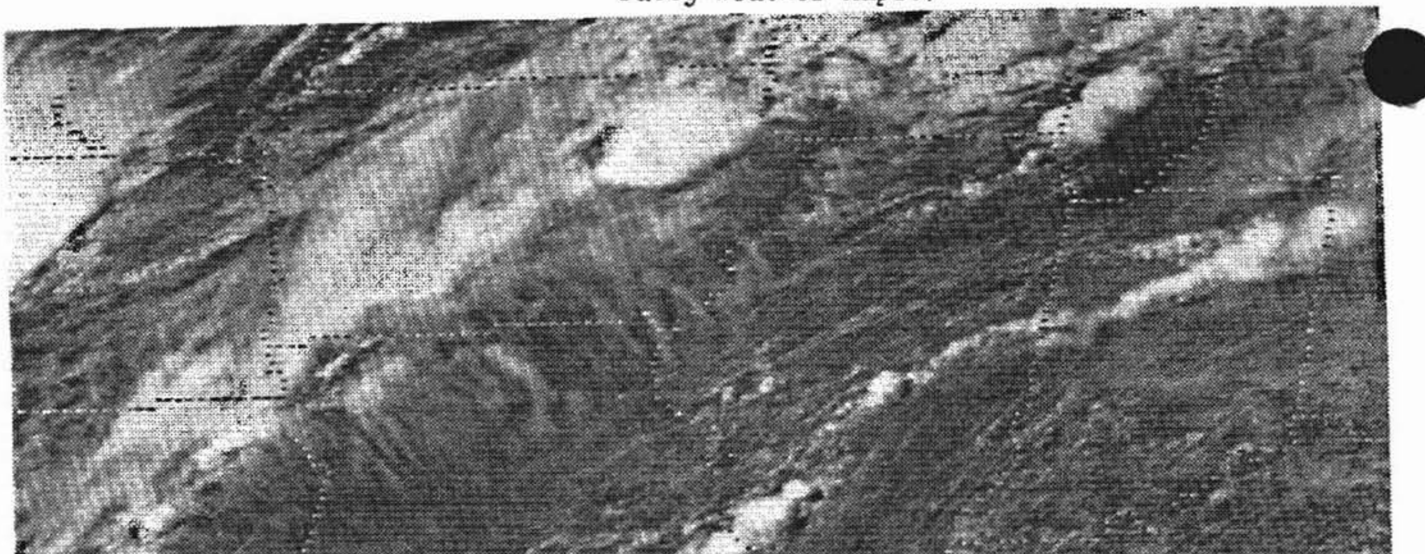


Fig. 2b. The MDCZ of 17 June 1984, a synoptic scale weather feature.

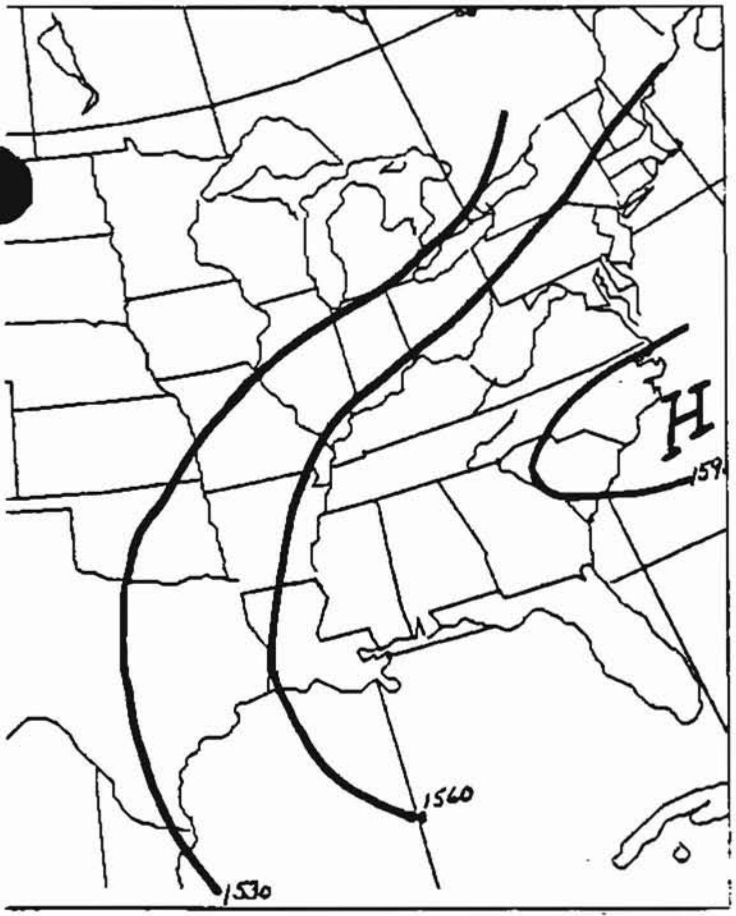


Fig. 2c. 850 mb.

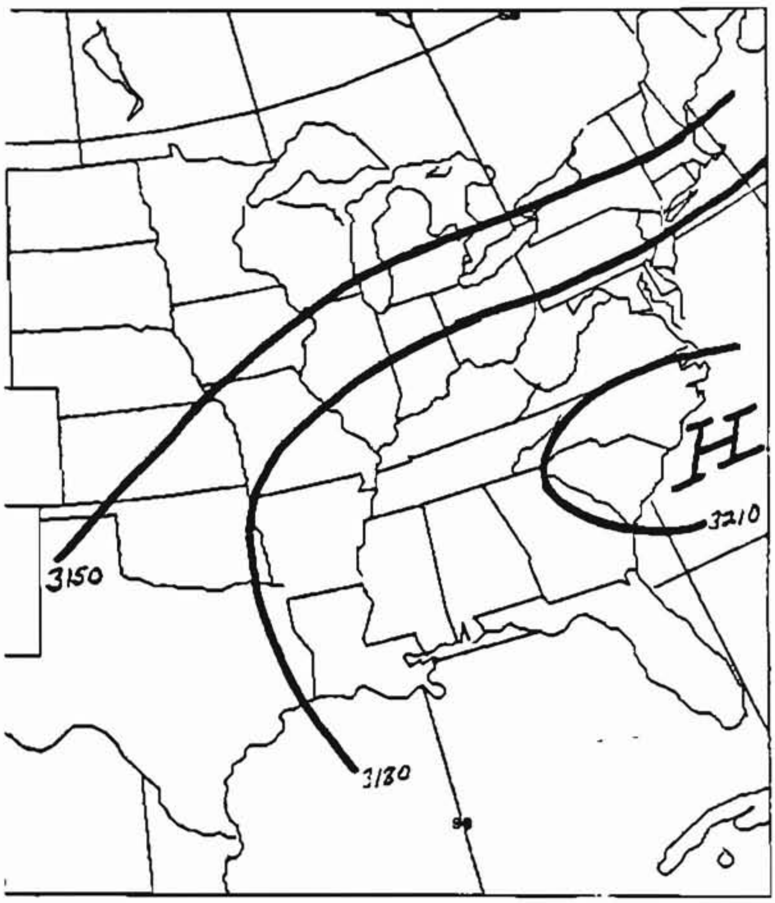


Fig. 2d. 700 mb.

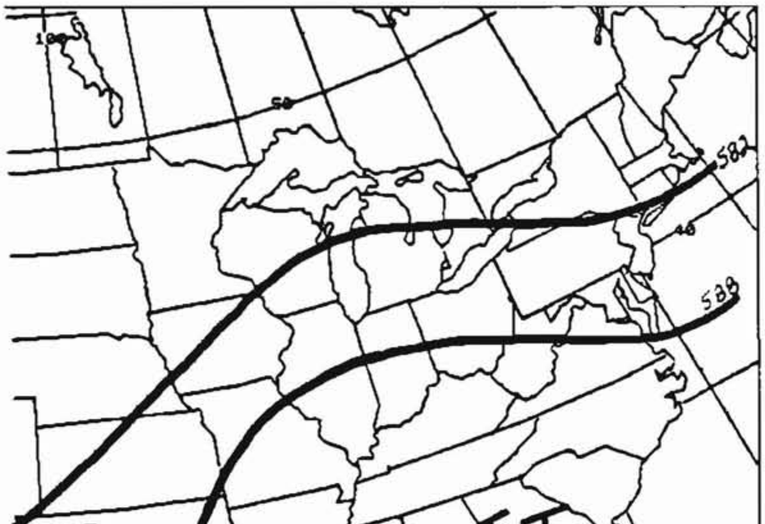


Fig. 2e. 500 mb.

Doswell (1982) which leads to the formation of a classic LLJ stream. In general, there is an anticyclone east of the Mississippi Valley and a trough to the lee of the Rocky Mountains. This synoptic setting allows maritime tropical air to flow up the Mississippi Valley. It is when a blocking high develops over the southeastern United States in the summer that unique conditions are set up for the formation of the MDCZ. The blocking high will generally keep the trough and associated fronts west of the Mississippi Valley.

The states of Missouri, Arkansas, Indiana and Illinois are then climatologically favored areas for the formation of an anticyclonic curving LLJ (which is often a northeast branch of a southern Plains LLJ) and the MDCZ. The southern Plains LLJ often feeds into a frontal system while the LLJ associated with the MDCZ curves around the western edge of the Bermuda High well ahead of the frontal zone. Four case studies of the MDCZ will be presented. They are the three days mentioned in the introduction plus one other day. Although this is a small sample the synoptic pattern is a common one, and a summer without several occurrences would be rare. I stress that the precise manner in which the LLJ causes a convergence zone has not been completely determined, but there appears to be little doubt that the LLJ is the mechanism for low-level convergence and thunderstorm formation.

Fig. 3 shows the 12 GMT wind profiles to 3000 m for three proximity upper air stations on five days of widespread cloud streets over the middle Mississippi Valley. On the three days marked by an arrow on Fig. 3, a distinct LLJ in excess of 20 knots is evident. A MDCZ developed on each of these three days. The large numbers with degree signs on Fig. 3 indicate the maximum turning of the wind between the first reported level above the surface and 2000 m AGL. The wind profiles were quite linear on the squall line days. An average wind profile for Monett, Missouri (UMN) is shown in Fig. 4. The striking wind profiles on these "ground jet" days are due to unique atmospheric conditions established on the western side of the Bermuda High.

When the blocking high dominates a barotropic atmosphere can result. The high pressure area is essentially of a tropical nature; however, on the western side of the high ahead of the frontal zone a strong surface pressure gradient can develop. In such a barotropic atmosphere the geostrophic wind can't increase with height (Hess, 1959), and theoretically the maximum wind would be at the surface if it weren't for frictional drag. Fig. 5 shows the 12 GMT wind profiles to 10 km in the proximity of the MDCZ on 17 June 1984, and indeed the maximum wind is just above the surface on all three profiles. Little temperature advection at low levels results in the quite linear wind profiles. For example, the following 850 mb temperatures (^{o}C) were noted on two MDCZ days along an 850 mb isobar north from the Gulf of Mexico: 12 June 1984, LCH 17, LIT 17, SLO 17, DET 17; and 17 June 1984, LCH 16, LIT 16, SLO 17,

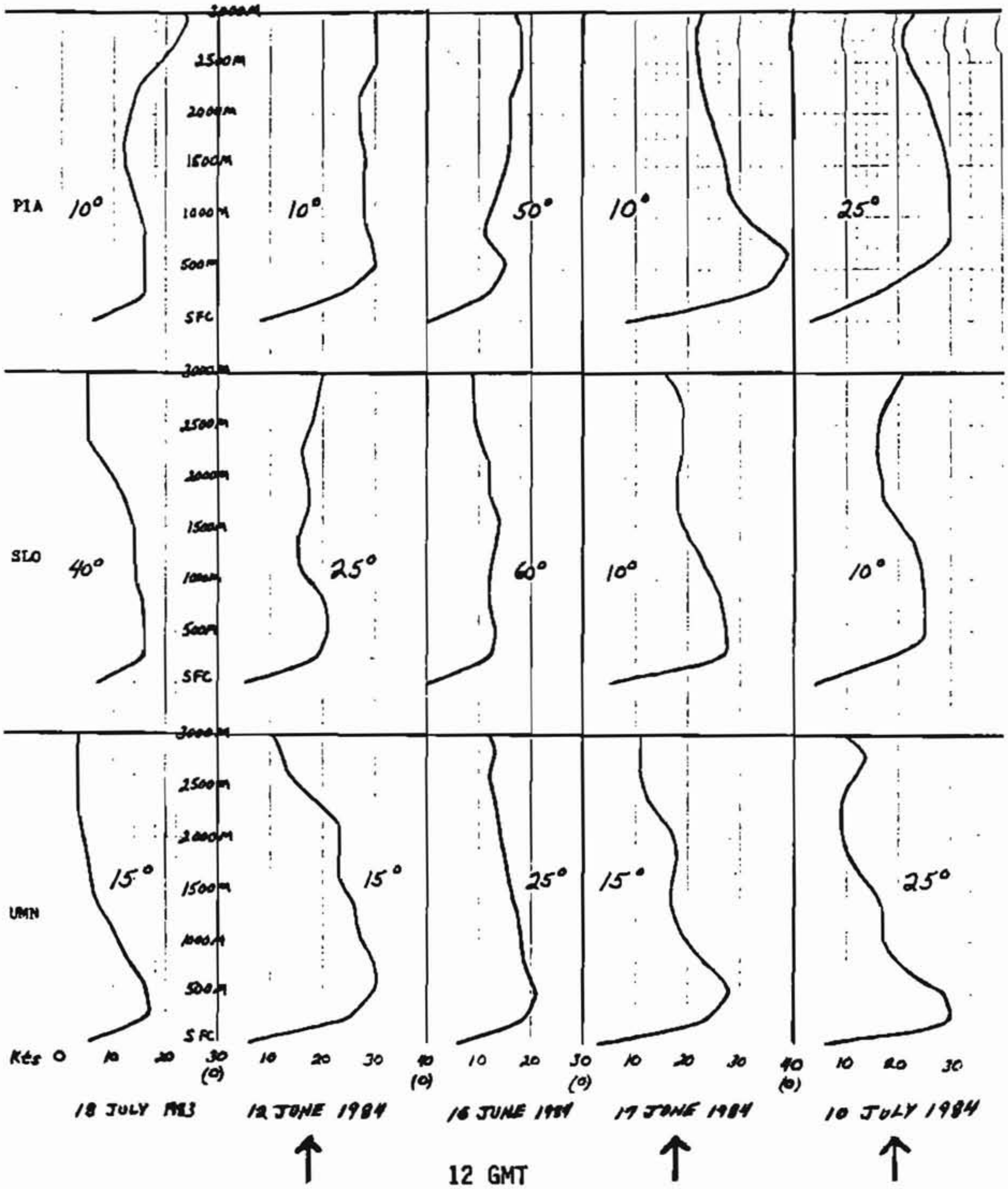


Fig. 3. Wind profiles to 3000 m for Peoria, IL (PIA, Monett, MO (UMN), and Salem, IL (SLO). The arrows indicate the days of the MDCZ and the large number in each block indicate the maximum change in wind direction between any levels from the very first level above the surface up to 2000 m.

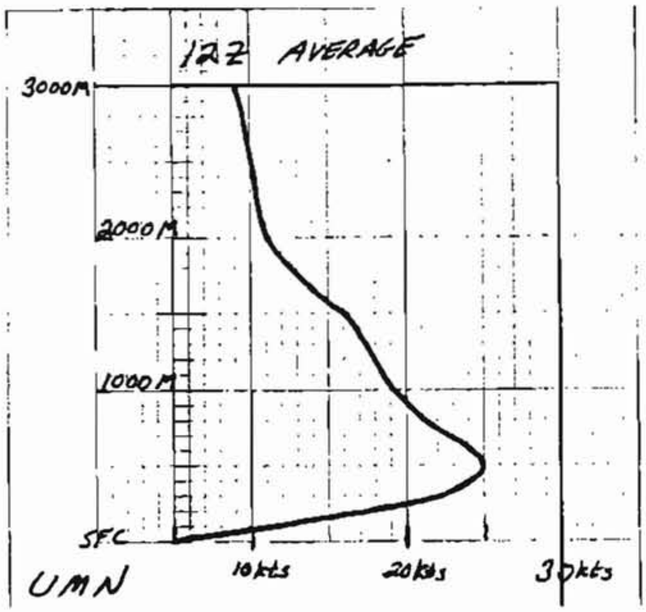


Fig. 4. Average wind profile for UMN for the five days on Fig. 3.

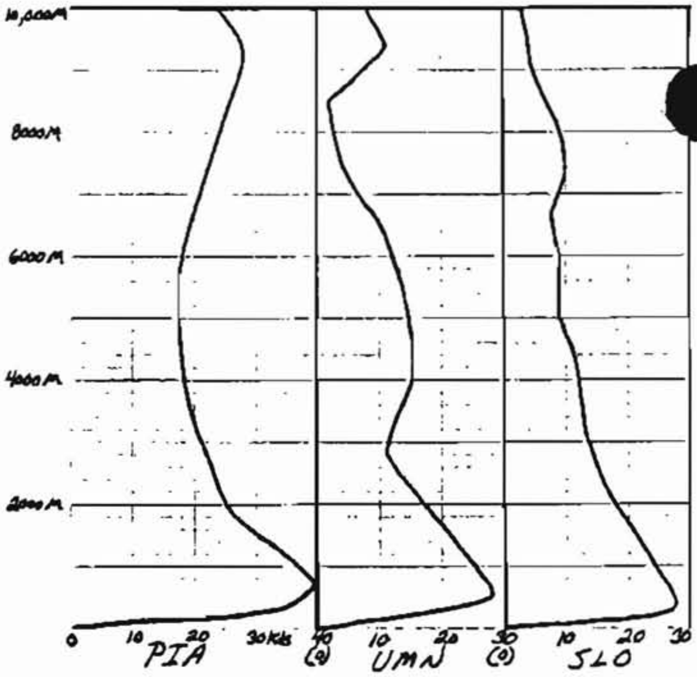


Fig. 5. 12 GMT wind profiles to 10 Km for 17 June 1984.

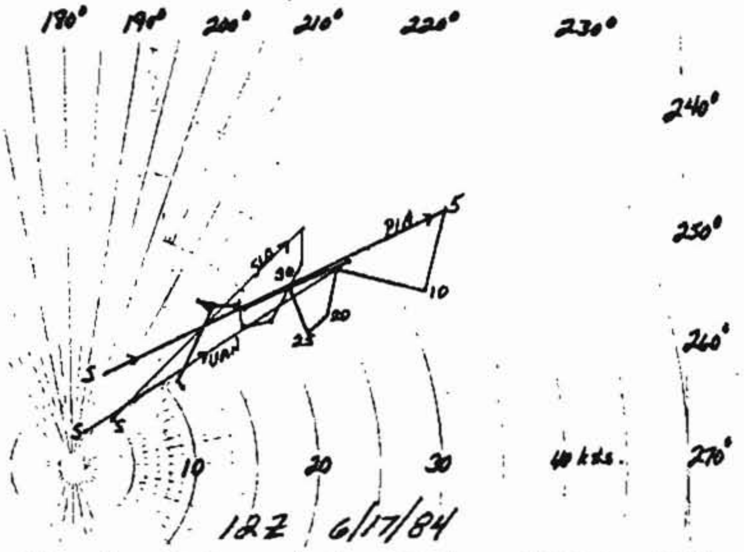


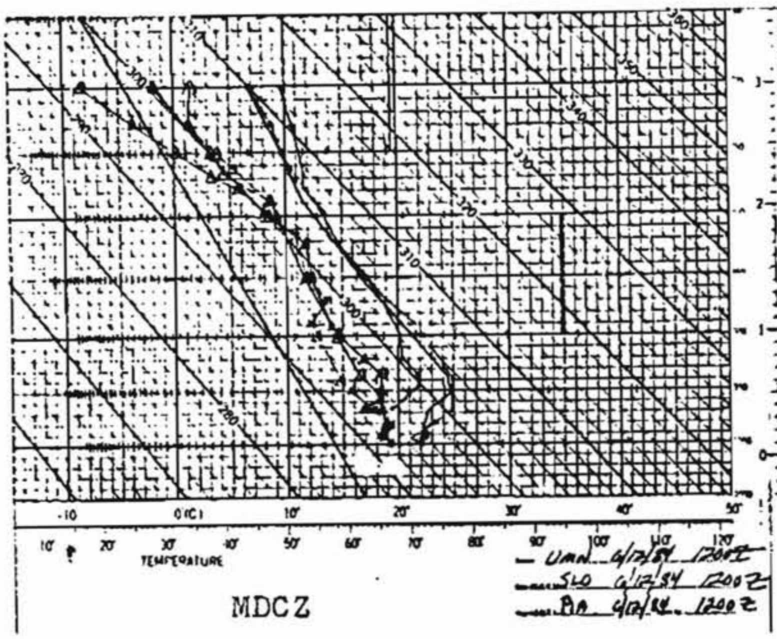
Fig. 6. Hodograph for 17 June 1984 to 3000 m. "S" denotes the surface wind and values are plotted every 500 m. The arrows indicate the vertical direction and the PIA plot is marked every 500 m.

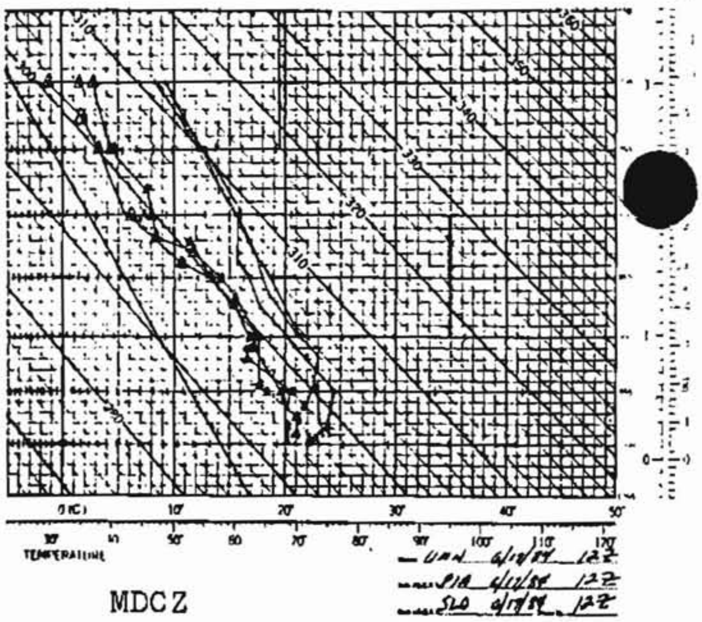
DAY 17, PIT 16. A hodograph to 3000 m for 17 June 1984 indicating the linearity of the three proximity soundings is shown in Fig. 6. The striking morning low level wind maxima on the MDCZ days are then due to a frictional decrease of wind below the level of the maximum and a decrease above due to the thermal wind. In general then, the anticyclone doesn't have a warm core and the LLJ isn't associated with warm air advection.

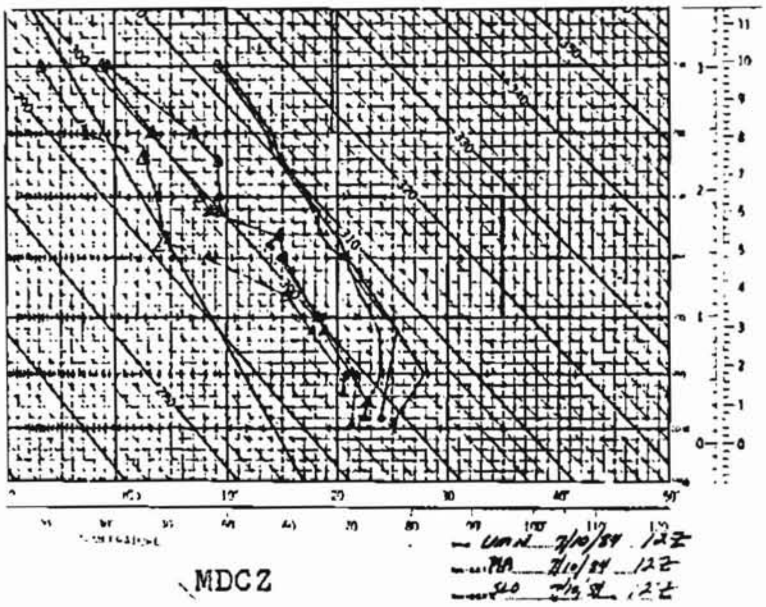
The summer "ground jet" provides the energy of the basic flow, but the boundary layer processes are the important links to the formation of the MDCZ. Unlike the classic LLJ stream, which often shows up at 850 mb, the ground jet is often entirely below 1000 m AGL. The boundary layer wind undergoes a significant diurnal inertial oscillation (Blackadar, 1957 and Sangster, 1967), and more precisely the strongly curved super geostrophic 12 GMT velocity profiles result from an early morning peak in the inertial oscillation, the decoupling (or boundary layer separation) of the surface flow due to a strong radiation inversion, and a thermal wind decrease with height. The low level vertical shear of the wind was observed to be as high as 30 knots in the first 300 m on some MDCZ wind profiles. Fig. 7 shows the soundings to 700 mb for each of the three MDCZ days and two cloud street days. In each case a low level inversion is clearly present.

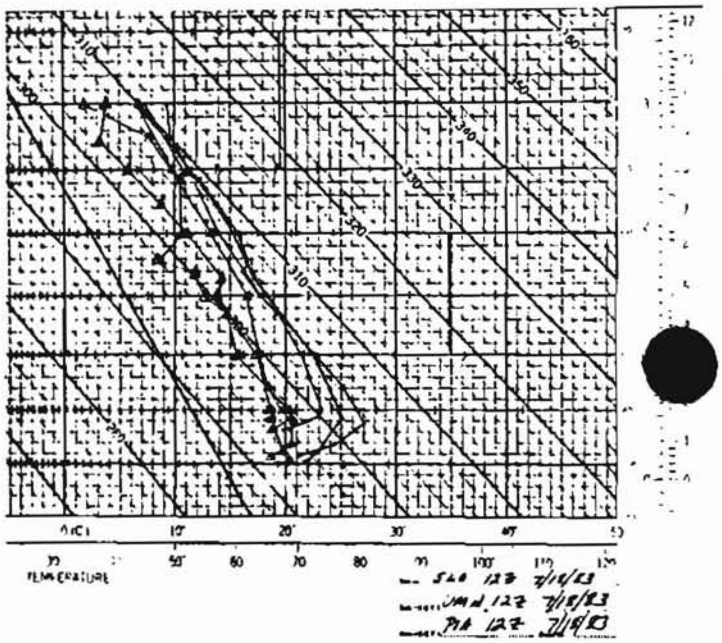
The MDCZ is strictly a daytime phenomenon and its diurnal course begins with clear morning skies. As the sun begins to heat and destabilize the underlying surface turbulent eddies mix down momentum from the LLJ and the surface winds increase and become gusty. The maximum low level wind should then occur at peak heating (Kuettner, 1959); however, this wind increase is not always reflected in surface observations. Along the LLJ axis a convergence zone and vertical motion field is established, with air currents converging on the axis and ascending. This complex process is beyond the scope of this paper, but is believed frictionally induced convergence and pumping of the boundary layer are crucial. It is interesting to note that on most of the case studies the zero surface vorticity line was near, and roughly parallel to, the analyzed LLJ axis. Since most of the vorticity came from horizontal shear rather than curvature this should be expected. Both the horizontal and vertical shear components of vorticity change sign at the LLJ axis.

Convergence is enhanced at the north end of the LLJ where the air decelerates and piles up, or where the curvature of the jet changes to cyclonic. In all four cases presented here squall lines developed either very near or to the right of the LLJ axis, or near the end of the LLJ axis. The strongest thunderstorms were observed at the north end of the MDCZ, and this is similar to Sangster's (1974) results on nocturnal Plains thunderstorms, but as to why the squall lines of the MDCZ should be to the right of the LLJ axis is unclear. Nevertheless, close inspection of the four cases in this paper indicates that enhanced









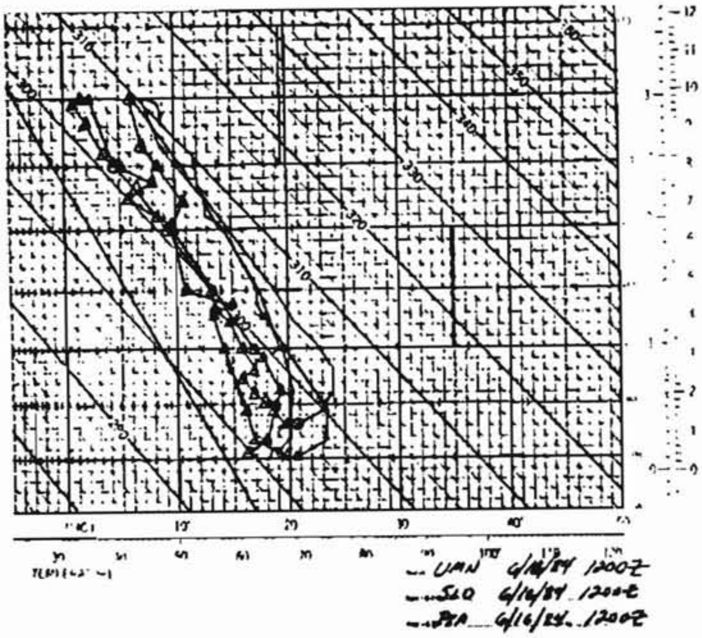


Fig. 7. Upper air soundings to 700 mb for the same days as Fig. 3. The first three days from left to right are MDCZ days.

convection formed either very near, or to the right of the LLJ axis. The vertical motion field of the LLJ axis may well be weak, but the synoptic setting of the MDCZ is generally characterized by very high low level moisture and a conditionally or convectively unstable atmosphere, and the lifting was clearly adequate on the case study days. The release of latent heat undoubtedly plays an important role in maintaining the MDCZ.

The strongly curved wind velocity profiles require that not only cloud streets, but squall lines be the naturally preferred arrangement of convection (Kuettner, 1959, 1971). The strength of the squall lines should reach a maximum shortly after peak heating, and this was the observed condition on the case study days. Over uniform terrain a squall line might develop all along the MDCZ; however, the rugged topography of the Ozark and Boston Mountain Regions disrupted the otherwise orderly MDCZ process, and true squall line development was only observed downwind of the Ozark Mountains. The much more turbulent flow and variable solar heating over the rugged terrain resulted in a wider area of scattered thunderstorms. It is believed that thunderstorms are possible wherever the LLJ impacts rugged terrain if stability and moisture values are adequate, not just near the LLJ axis.

The three squall line day soundings on Fig. 7 are characterized by mid-level drying while the weaker flow, cloud street days were characterized by high mid-level moisture which may have acted to choke off strong convection in the absence of synoptic forcing.

As solar heating decreases rapidly in late afternoon the MDCZ begins to weaken rapidly. The boundary layer begins to stabilize and the frictional convergence mechanism is turned off. Usually by nightfall the MDCZ has returned to clear skies. The simplest description of the MDCZ in its purest form is that it is turned on at sunrise and turned off at sunset. It starts and ends with clear skies.

3. FOUR CASE STUDIES

A. 17 June 1984

At 12 GMT a cold front cut across Nebraska from northeast to southwest and a warm front was over central Wisconsin and central Michigan. A LLJ from Oklahoma to northern Indiana was evident on the 12 GMT surface geostrophic chart. Skies were clear over the LLJ area and surface dew points were around 70°F. Stability indices were quite favorable for thunderstorm formation (K-index: SLO 27, UMN 33, and PIA 33; Lifted index: SLO -3, UMN -2; Showalter index: SLO +1, PIA 0, and UMN 0). The first indication that the MDCZ would form came at 1430 GMT when a streak of cumulus was seen across central Illinois near the LLJ axis on GOES data (see Section 4). By 1830 GMT a squall line had formed over central Illinois and northern Indiana very near, or just to the right, of the LLJ axis (Figs. 8a and b). Fig. 9 shows the squall line on Marseilles, Illinois weather radar at 1844 GMT. The squall line was oriented parallel to the 12 GMT maximum low level wind vector at Peoria, Illinois, and the strongest thunderstorms were at the northern end of the MDCZ. By 21 GMT the squall line had intensified considerably and extended from just downwind of St. Louis, Missouri to northwest Ohio (refer back to Fig. 2b). There were no verified severe weather occurrences associated with this squall line. The GOES satellite photos between 18 GMT and 2130 GMT, and a high resolution NOAA 7 photo taken at 2102 GMT, clearly showed cloud streets converging into the squall line. Note that the wider area of scattered thunderstorms over the Ozark Mountain Region narrowed to a distinct line over the nearly level terrain of Indiana and Illinois. By 22 GMT all thunderstorms had weakened considerably.

B. 10 July 1984

The synoptic setting of this day was quite similar to the previous case study day. A LLJ axis was clearly indicated on the 12 GMT surface geostrophic chart from eastern Oklahoma to central Indiana. Skies were clear over the LLJ area except for scattered middle and high clouds over eastern Indiana. Surface dew points ranged from a high around 75°F in Indiana to around 65°F in Oklahoma. Stability indices for SLO, PIA and UMN respectively were: K-index, 32, 32, and 18; Showalter index, -1, -3, and +5. The first indication of the formation of the MDCZ on satellite photos came at 1530 GMT (see Appendix). As a result of the much more stable air over the Ozark Mountain Region only scattered rainshowers were observed to form there while strong thunderstorms formed in central and northern Indiana. The LLJ axis moved to northern Indiana between 12 GMT and 18 GMT and several parallel squall lines were observed to form in the quite unstable air near the axis by 1931 GMT. By 2031 GMT two distinct squall lines had formed, one to the right of the LLJ axis, and the other apparently along the LLJ axis at the exit region. The squall line at the LLJ exit consolidated into a thunderstorm complex with overshooting tops by 21 GMT, while the squall line to the right of the LLJ axis persisted an hour longer before turning into a single thunderstorm complex. Fig. 10 shows the location of the LLJ axis on the surface geostrophic chart at 21 GMT, and Fig. 11 shows the corresponding satellite photo. Radar film of the area indicated that echoes were converging along the axis where the LLJ was decelerating. Fig. 12 shows the intersecting trajectories of echoes from two adjacent squall lines. The merger of these thunderstorms resulted in the strong thunderstorm complex at the LLJ exit in Fig. 11 forty minutes later. The squall line to the right of the LLJ axis on Fig. 12 isn't completely drawn in. Around 23 GMT a large tree was blown down and marble size hail was reported near Pennville in northeast Indiana (see 2301 GMT photo in Appendix). See the Appendix for a complete sequence of GOES photos for this day.

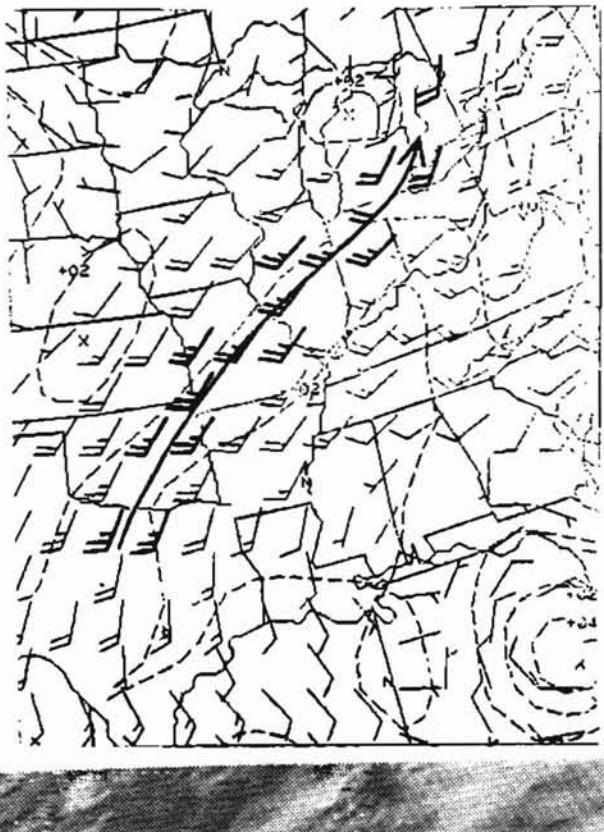


Fig. 8a. The 18 GMT surface geostrophic chart for 17 June 1984. The LLJ axis is indicated by the black line.

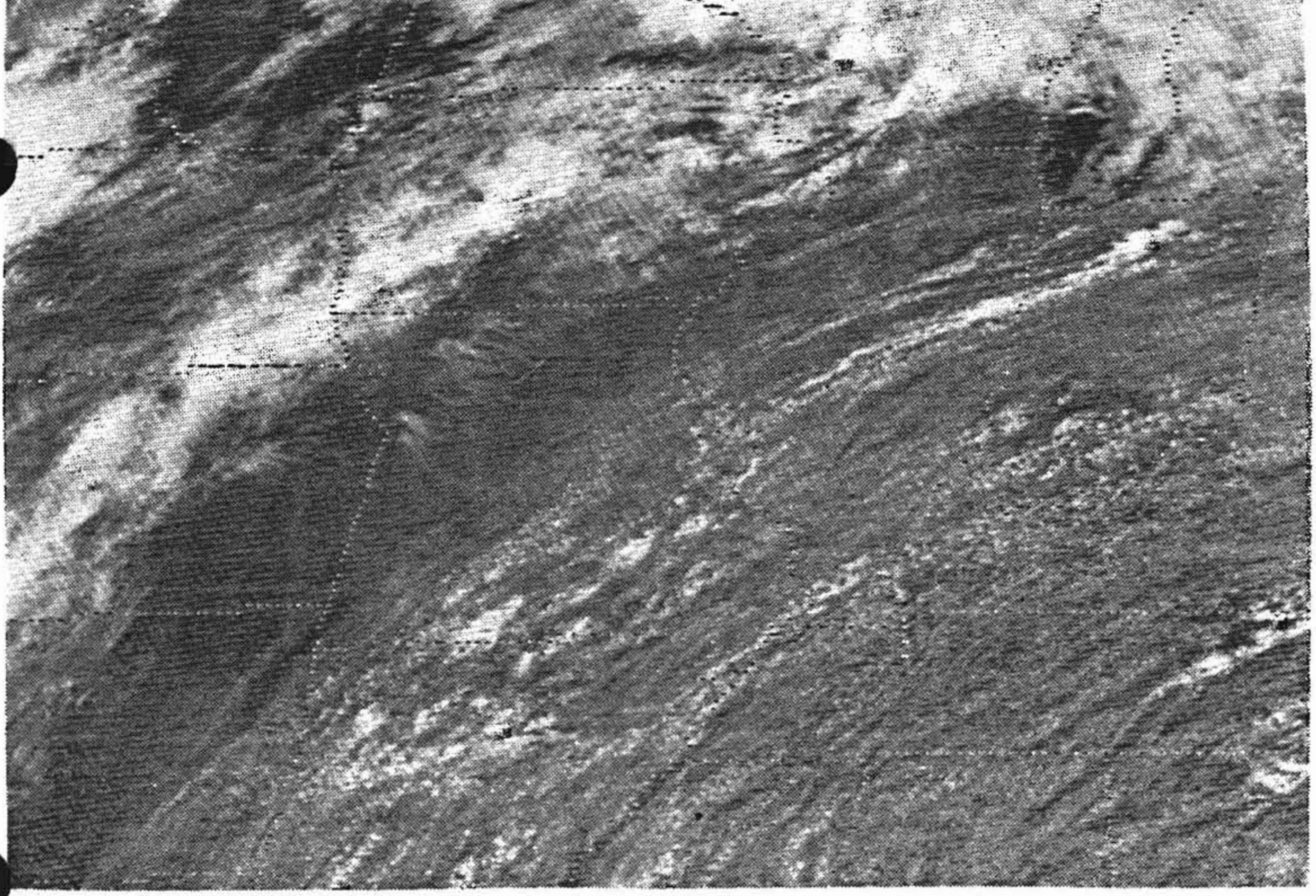


Fig. 8b. 1830 GMT GOES picture for 17 June 1984.

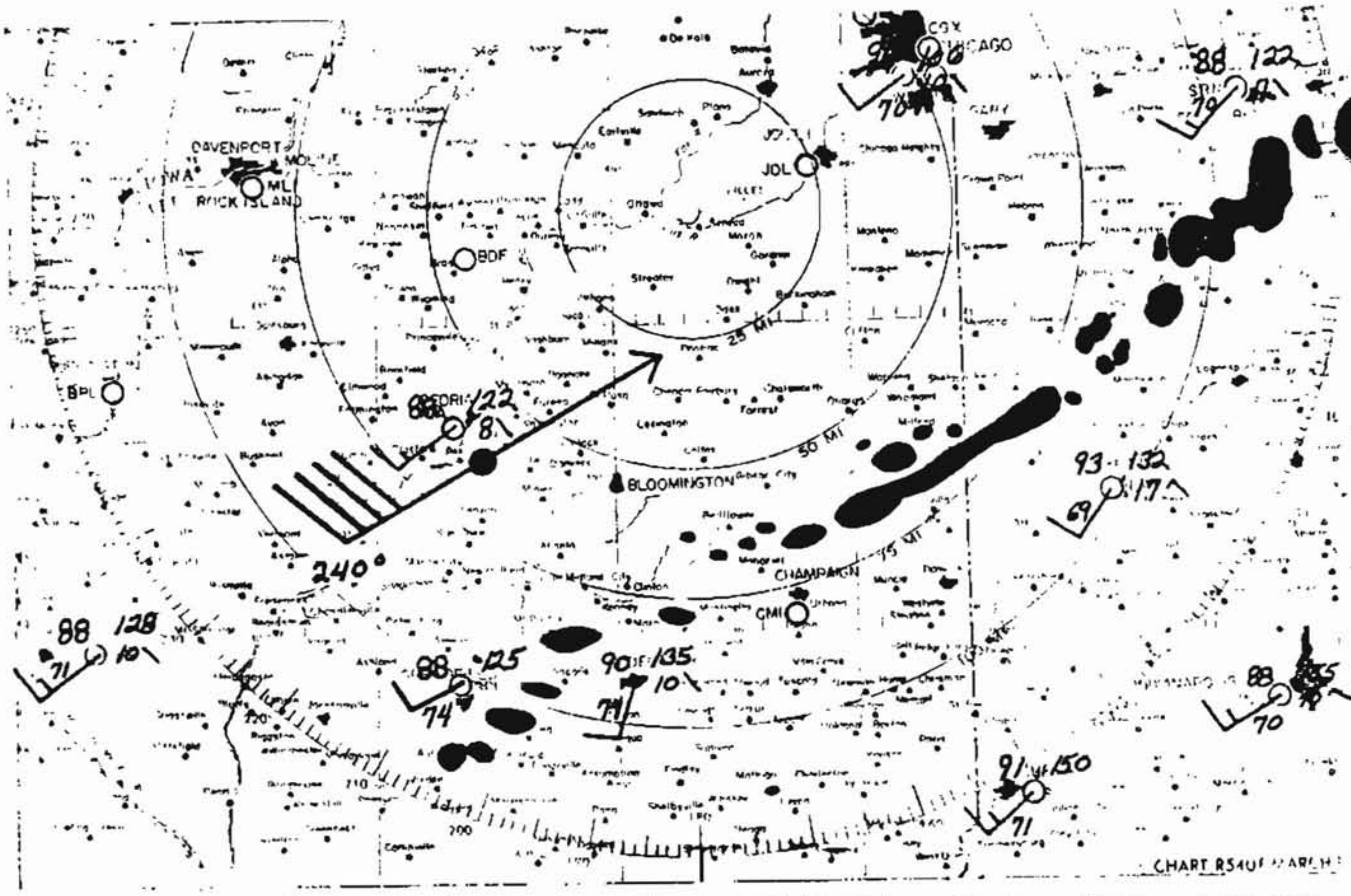


Fig. 9. Marseilles, IL radar presentation at 1844 GMT on 17 June 1984 and 18 GMT surface observations. Maximum low-level wind at Peoria is also shown.

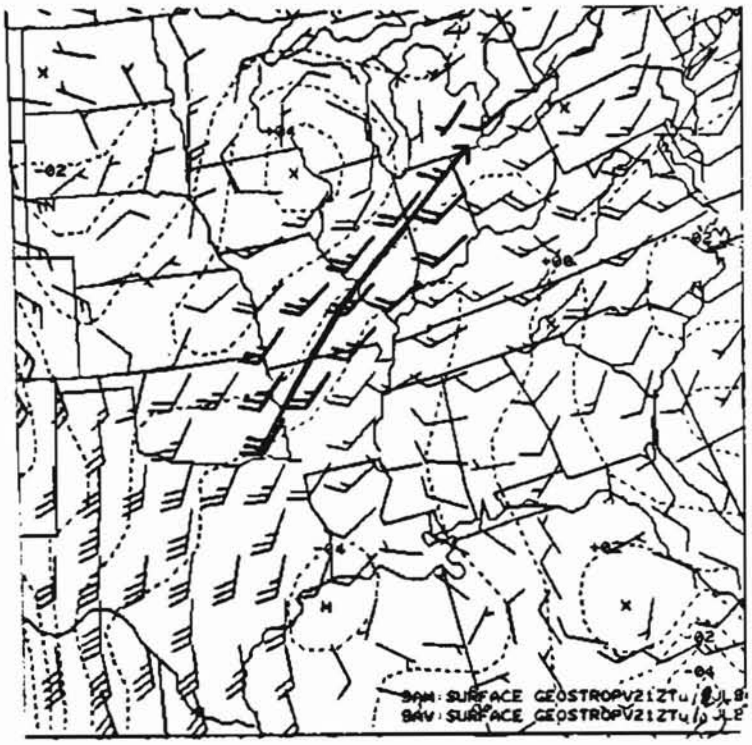


Fig. 10. Surface geostrophic chart for 21 GMT on 10 July 1984.

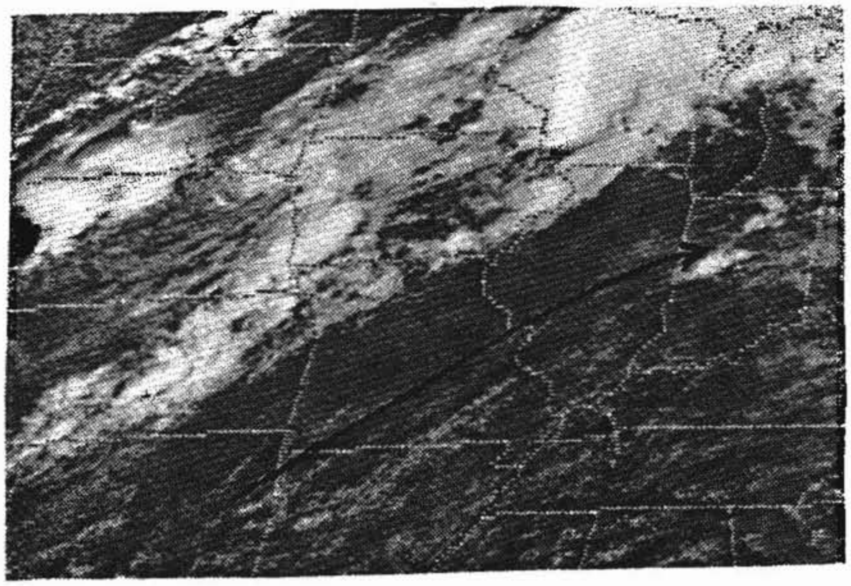


Fig. 11. GOES 2101 GMT 10 July 1984.

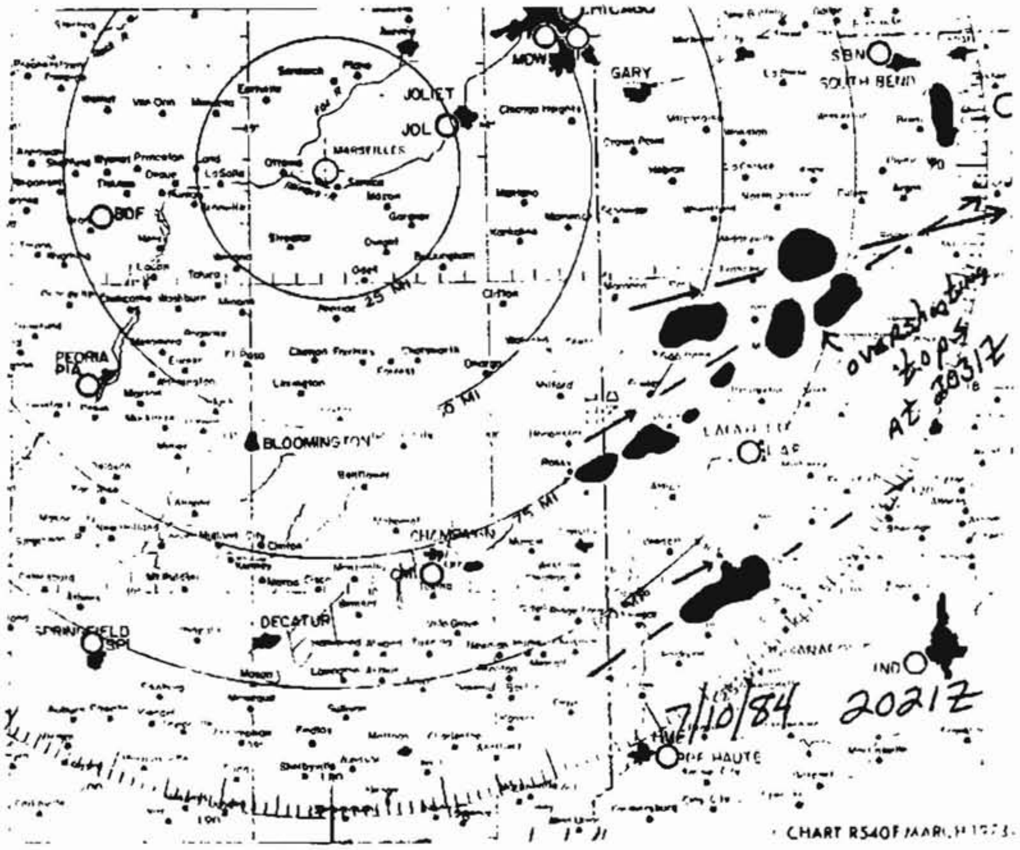


Fig. 12. Marseilles, IL radar at 2021 GMT on 10 July 1984. The thunderstorms of the two squall lines near the LLJ axis were on intersecting trajectories between 1930 and 2021 GMT. A strong thunderstorm with overshooting tops had resulted by 2031 GMT.

C. 9 June 1984

This case study isn't one of the original three discovered, but was found by synoptic pattern recognition. It is not a significant case from the standpoint of thunderstorms produced, but it is the most important of all four cases for demonstrating the effect of the LLJ axis because it was a day in which the LLJ was remarkably well delineated by the cumulus field over relatively level terrain. In order to see the effect of the LLJ axis itself it is probably better to observe its course through a cumulus field devoid of thunderstorms and study the resulting patterns. Once strong convection has occurred one is no longer able to isolate the effect of the LLJ.

The 12 GMT wind profile for Salem, Illinois is shown in Fig. 13 and the temperature and dew point profile is shown in Fig. 14. The wind profile was strikingly linear, varying by no more than 10^{o}. The 12 GMT surface geostrophic chart (Fig. 15) shows that Salem was near the LLJ axis. Although a strong LLJ was present the atmosphere was clearly unfavorable for thunderstorm formation. The Showalter index was +11, and the lifted index was +3. The LLJ axis was nearly in the same location at 15 GMT (Fig. 16). A satellite photo taken at 1631 GMT (Fig. 17) shows the remarkable correlation between the LLJ axis and "enhanced" cumulus clouds. The back edge of the enhanced clouds, generally indicated by a distinct clear line, can be easily traced from just west of the Missouri Bootheel to southwestern Lake Erie. Surprisingly, the LLJ disappeared on the 18 GMT surface geostrophic chart (Fig. 18), but a LLJ axis was clearly indicated on the 18 GMT surface analysis from Memphis, Tennessee to South Bend, Indiana (Fig. 19). Something unusual was obviously occurring because the observed surface winds at the northern end of the LLJ were as much as 50% higher than the computed surface geostrophic wind. The LLJ axis had shifted considerably in three hours, but the 1900 GMT satellite photo (Fig. 20) clearly indicates that the cumulus field responded to the change in the axis position. On Fig. 20, the LLJ axis can be seen coursing through the cumulus field from near Memphis, Tennessee to southern Michigan. Enhanced cumulus are at the jet entrance and exit regions (see arrows in Figure 20). A narrow and distinct clear line can also be seen adjacent to the enhanced cumulus clouds from extreme southeast Missouri to near South Bend, Indiana. The cumulus field is still disturbed, but unorganized on Fig. 20 near the previous position of the LLJ axis.

At 21 GMT the LLJ axis was still clearly evident from Memphis to South Bend in the surface analysis (Fig. 21). A 22 GMT satellite photo (Fig. 22) shows the remarkable correlation between the LLJ axis position and the squall line location at the northern end of the MDCZ. An enhanced cloud band is also evident at the LLJ entrance region. The cloud lines at the LLJ exit and entrance regions can easily be seen to

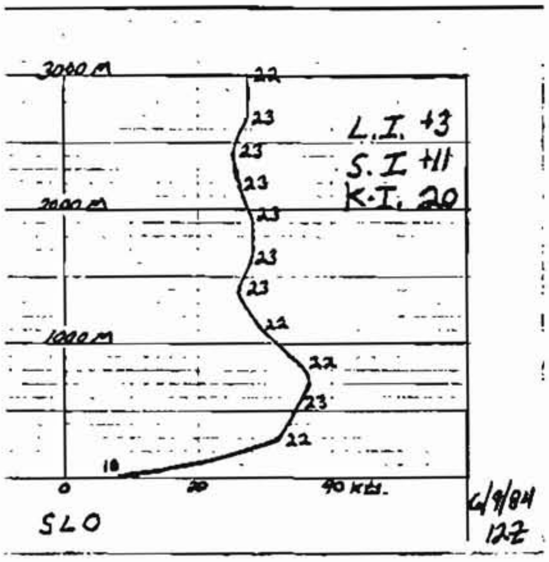


Fig. 13. 12 GMT wind profile for Salem, IL on 9 June 1984. Wind direction is in 10's of degrees.

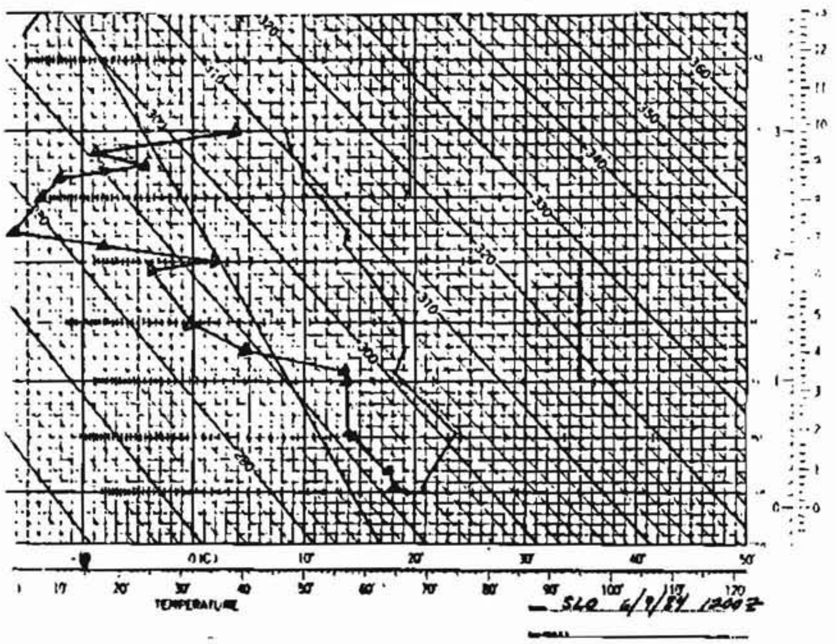


Fig. 14. 12 GMT sounding to 700 mb for Salem on 9 June 1984.

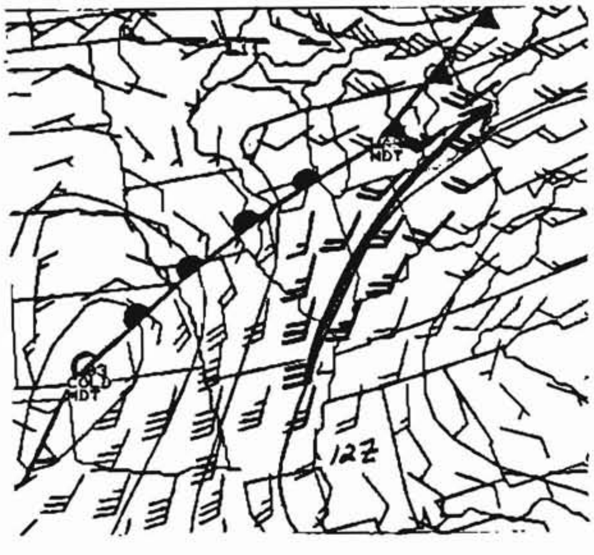


Fig. 15. Surface geostrophic wind, fronts, and isobars at 12 GMT.

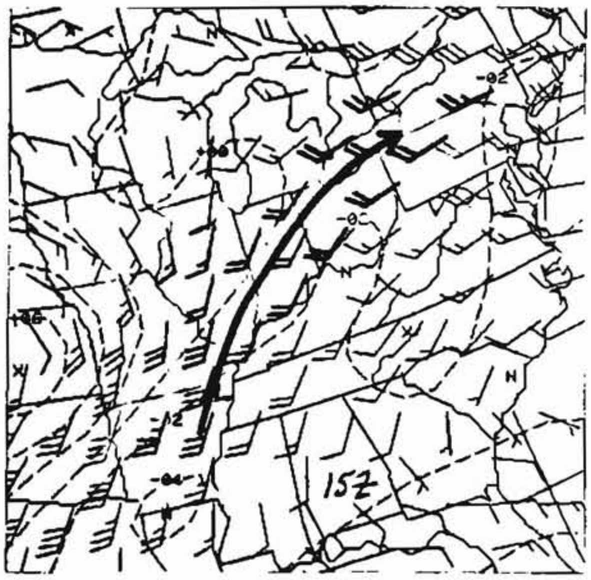


Fig. 16. 15 GMT surface geostrophic wind chart.

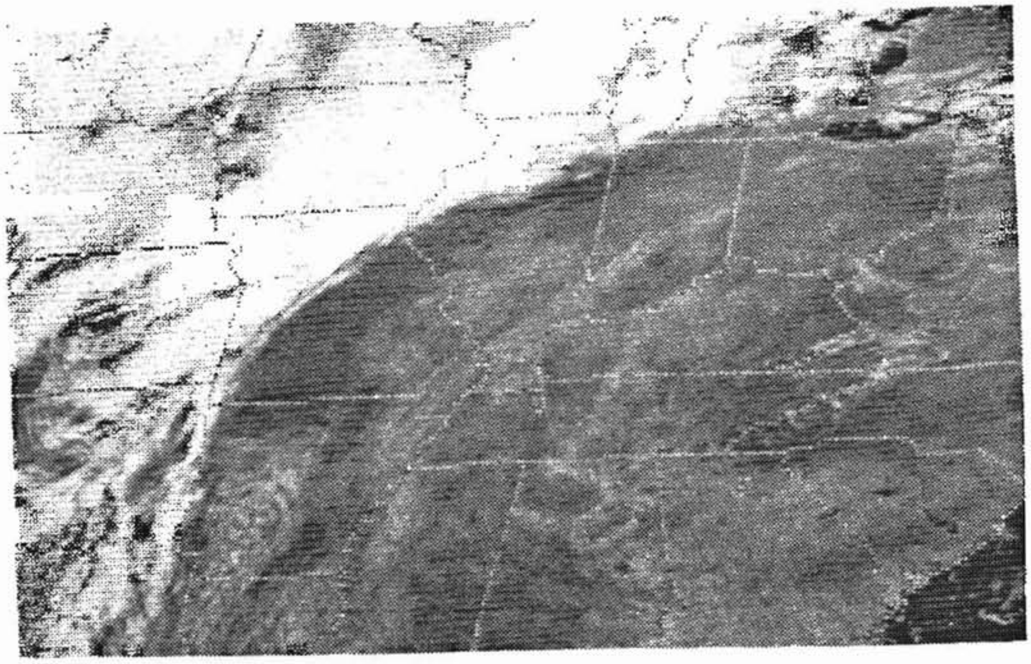


Fig. 17. 1631 GMT 9 June 1984.

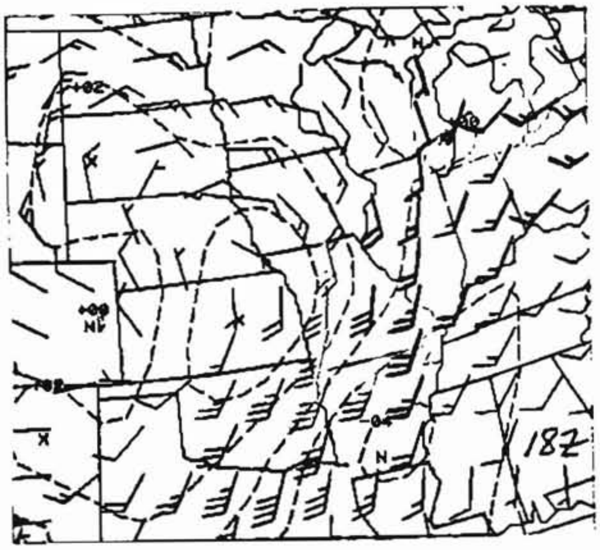


Fig. 18. 18 GMT surface geostrophic wind chart showing diffluence where the surface analysis indicates a LLJ.

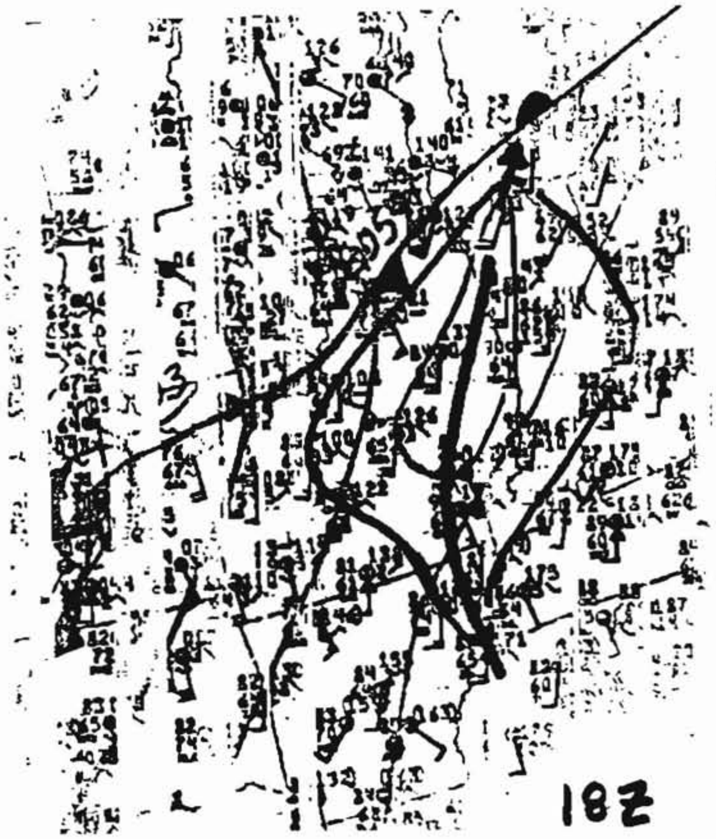


Fig. 19. 18 GMT surface analysis. The LLJ axis and 15 and 20 knot isotachs are shown.

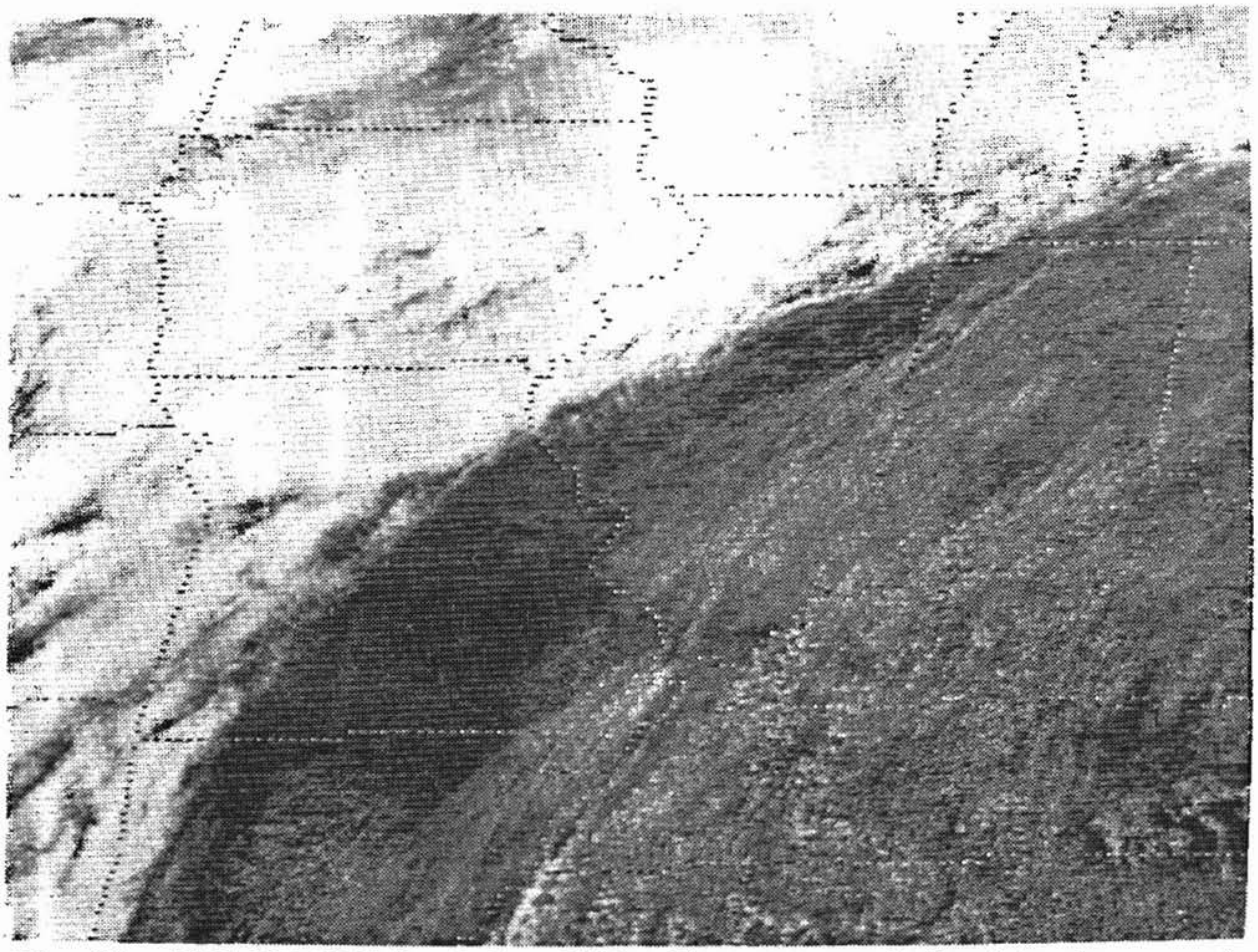


Fig. 20. 1900 GMT GOES for 9 June 1984. The arrows mark the jet entrance and exit regions.

Fig. 21. 21 GMT surface analysis with LLJ axis and 15 and 20 knot isotachs analyzed.

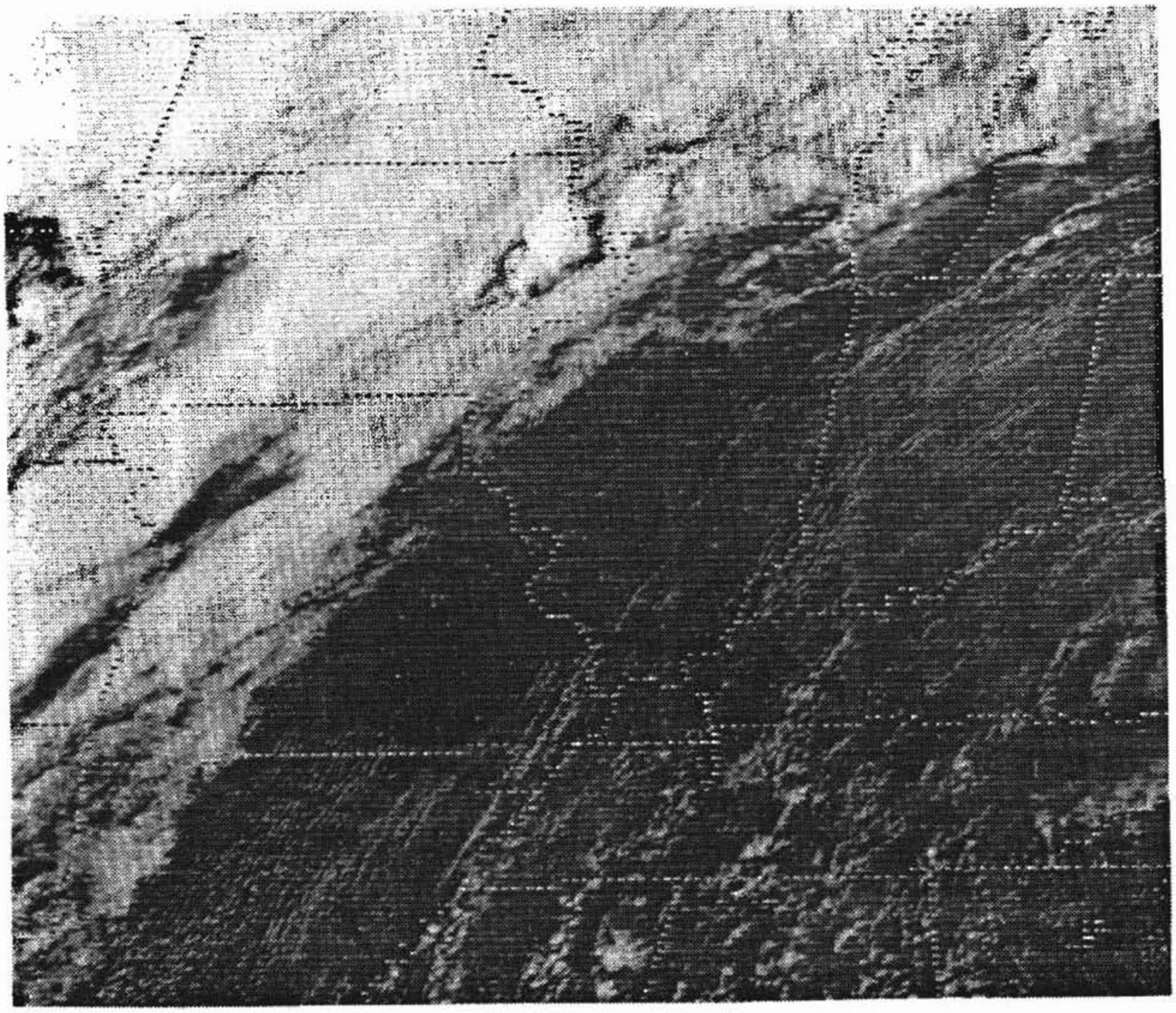


Fig. 22. GOES 2200 GMT 9 June 1984.

lie on the same axis. One can't be entirely sure whether the convergence zone is directly on the axis or just to the left or right without more detailed data, but the available data leaves little doubt that the LLJ axis is closely associated with, and probably the cause of, the organized convection.

D. 12 June 1984

This case is presented last because it's not a "pure" case of the MDCZ. At 12 GMT a cold front was located over the central Plains and a weak warm front was located along the western border of Illinois. Despite the presence of the warm front (which was really a "moisture front") there was no indication of warm air advection at Salem or Peoria, and skies were clear from northeastern Oklahoma to southern Michigan. The 12 GMT surface geostrophic chart indicated a relatively short LLJ axis from near St. Louis, Missouri to Milwaukee, Wisconsin. Stability indices for SLO, PIA and UMN respectively were: Showalter index: 0, 0, 0; Lifted index: -3, -1, -1; and K-index: 32, 29, 23. Between 12 and 15 GMT the warm front moved rapidly northeast ot southern Michigan, and the surface dew point at SBN rose from 51 to 62°F. The 15 GMT surface geostrophic chart indicated a LLJ axis from southwest Missouri to northeast Missouri to Michigan's Upper Peninsula. By 18 GMT the northern end of the LLJ axis had moved southeast and convection was breaking out well to the right of the LLJ axis (Figs. 23a and b). Unfortunately, no GOES data were available between 16 and 18 GMT to see the beginning of the MDCZ process. Looking at Fig. 23b one might be tempted to think that, as in the other cases, the LLJ axis would be much further right near the convective clouds. However, this case was much more complex. Not only was the LLJ axis moving rather rapidly through the atmosphere, but significant low level moisture advection was occurring over northern Indiana. Additionally, a large nocturnal thunderstorm complex dissipated over Iowa during the morning, thus establishing an outflow boundary over northern Illinois. The moving LLJ axis may have actually marked the outflow boundary as the day progressed. These complexities make the simple assumptions of the three previous cases invalid. Nevertheless, in recognizing the pattern and working with just the 18 GMT satellite data one should expect significant thunderstorm development over Indiana during the afternoon. Figures 24a and 24b show the resulting strong thunderstorm development over the northwest half of Indiana at 2030 GMT and the new position of the LLJ axis at 21 GMT. Unfortunately, the LLJ axis couldn't be tracked in the surface observations to check the position of the surface geostrophic derived axis position. Low-level convergence is strongly implied over Indiana on the 2030 GMT satellite photo. A short-lived tornado tore the roof off of a house near Logansport, Indiana at 2005 GMT and a pilot reported a tornado near Lafayette, Indiana at 2028 GMT. It is interesting to note that the LLJ didn't decelerate over northern Indiana, but curved cyclonically before intersecting the warm front over Lake Huron. Nevertheless, the strong

Fig. 23a. 18 GMT surface geostrophic for 12 June 1984.

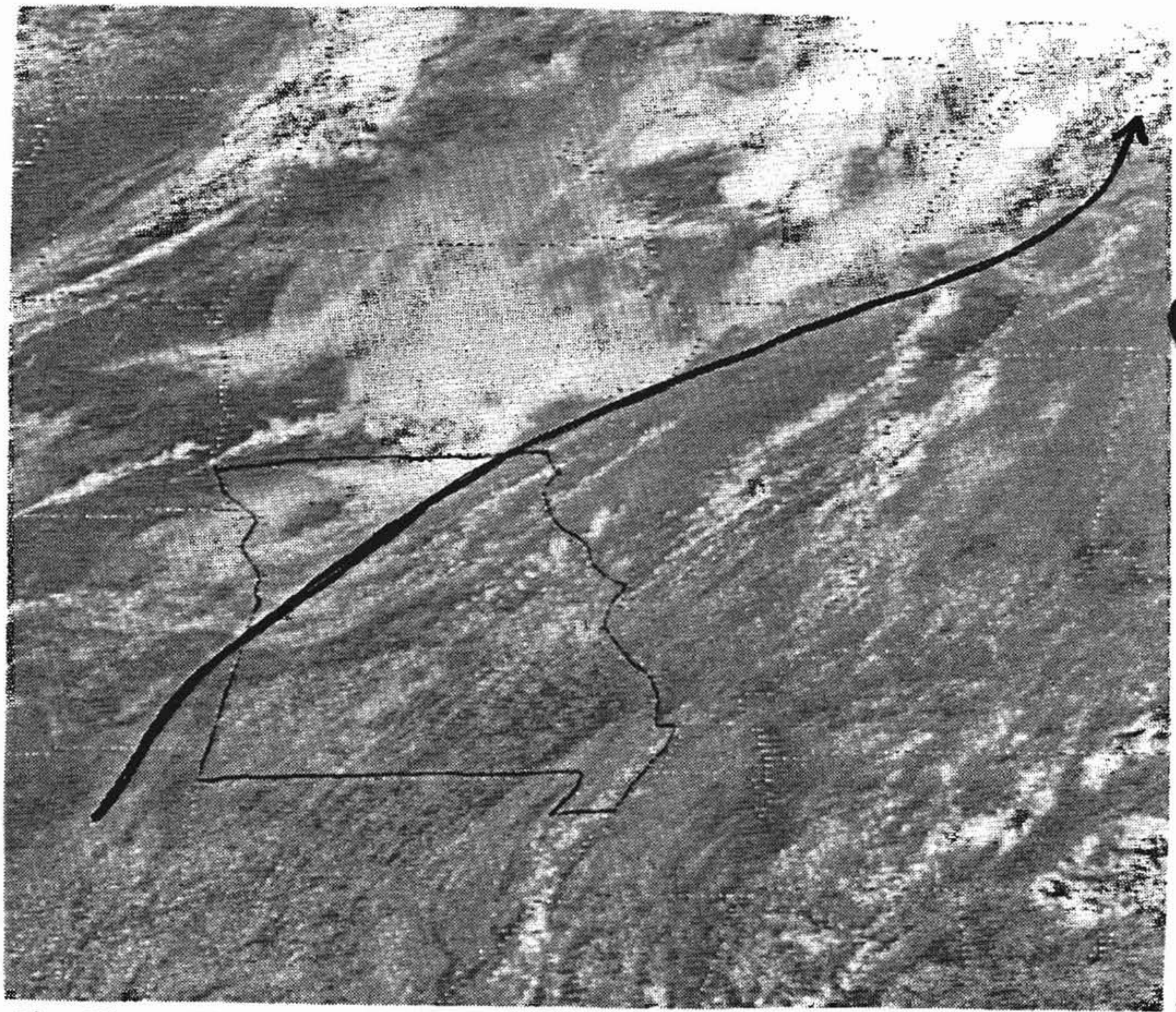


Fig. 23b. GOES 18 GMT 12 June 1984. The approximate LLJ axis is shown in white.

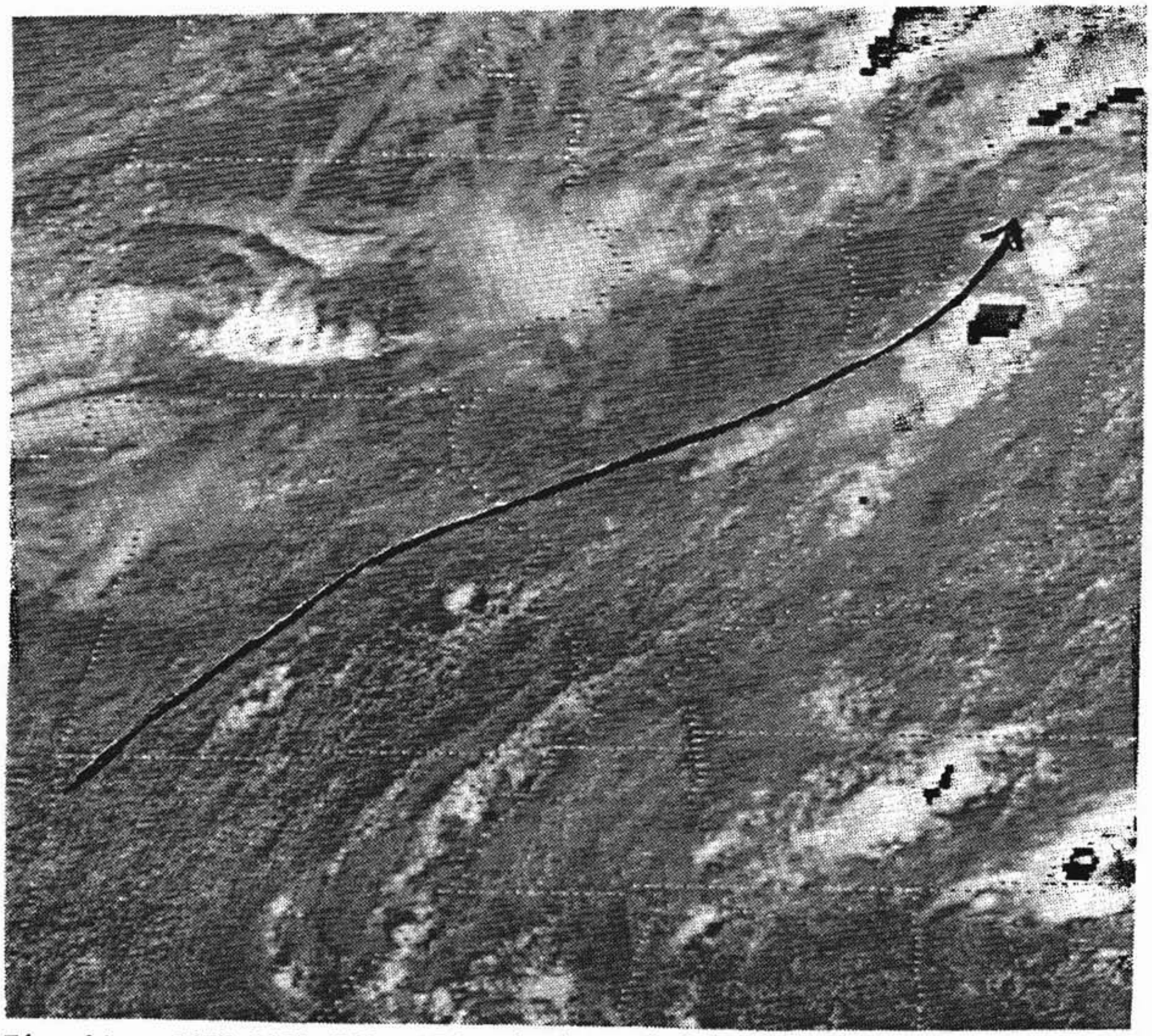


Fig. 24a. GOES 2030 GMT. LLJ axis is marked by a dark line with arrow. A tornado touched down briefly in North Central Indiana at 2005 GMT.

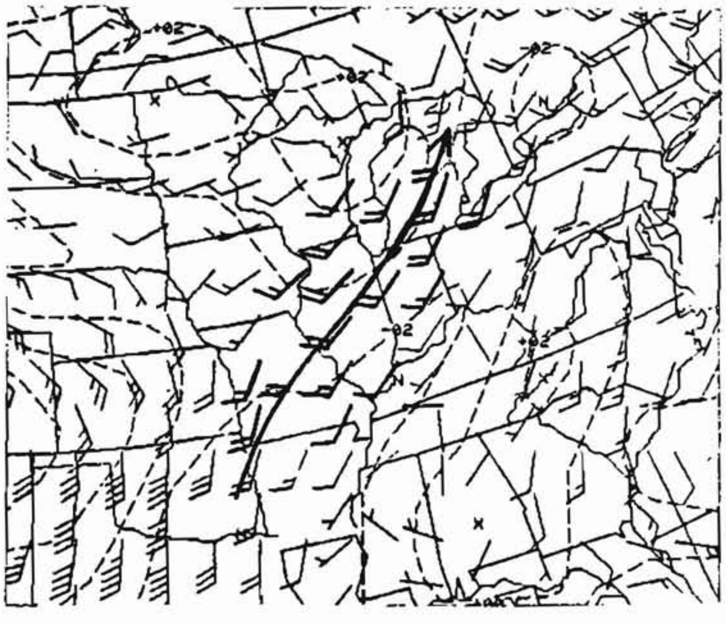


Fig. 24b. 21 GMT surface geostrophic winds.

thunderstorms associated with the MDCZ formed over northern Indiana and never progressed beyond the anticyclonic curving portion of the LLJ. By 0000 GMT on the 13th the thunderstorms had dissipated and skies had become virtually clear over the MDCZ area.

4. FORECASTING THE MIDWESTERN DIURNAL CONVERGENCE ZONE

Given adequate low level moisture and instability a forecaster could quite accurately predict the location of the MDCZ and subsequent thunderstorm development if he or she could pinpoint where the LLJ axis would be during peak afternoon heating. Since this isn't exactly possible, the following approach is recommended for forecasting the MDCZ:

The first step is to recognize the synoptic setting likely to produce the MDCZ a la Fig. 2a-e. Then look at the 12 GMT surface geostrophic wind chart for any indication of a LLJ and analyze for the axis (Fig. 25). A look at the 12 GMT surface analysis will also give an intuitive indication of the general location of the LLJ and subsequent MDCZ formation (the hatched area in Fig. 26). Next look at the proximity upper air messages for evidence of a LLJ wind profile like those in Figs. 3 or 4. The stronger the jet and the less the turning of the wind with height at low levels the better. If all indications are positive at this point then satellite and surface observations should be monitored for evidence of the MDCZ process beginning before forecast release time. Fig. 27 shows a streak of cumulus over central Illinois associated with the LLJ at 1430 GMT and Fig. 28 shows winds increasing at South Bend, Indiana. On Fig. 28 the LLJ axis is drawn through the cumulus streak downwind to SBN and upwind, paralleling the wind direction to near Fort Smith, Arkansas. Squall line development should now be expected over central Illinois, northern Indiana, and southern Michigan, on or to the right of the axis, while scattered thunderstorms should be expected over the Ozark Mountain Region. Referring back to Figs. 2b and 8b, one can see how accurate this method can be. Of course, this method is best applied when, as on this day, the LLJ axis didn't move much between morning and afternoon. Unfortunately, none of the other cases were quite this easy.

The LLJ often doesn't show up in the surface observations, and the MDCZ process may not be evident in satellite pictures before forecast release time. Satellite data give the most accurate position of the LLJ axis and the developing MDCZ. The first cumulus clouds should form along or near the LLJ axis and the axis can be easily analyzed (see the 1530 GMT photo in the appendix, the axis is evident from northwest Arkansas to central Indiana). If the satellite derived axis matches the surface geostrophic wind axis, fine; if it doesn't, look at the surface observation. If the surface observations don't indicate an axis then stick with the satellite data. Although it may be too late for forecast

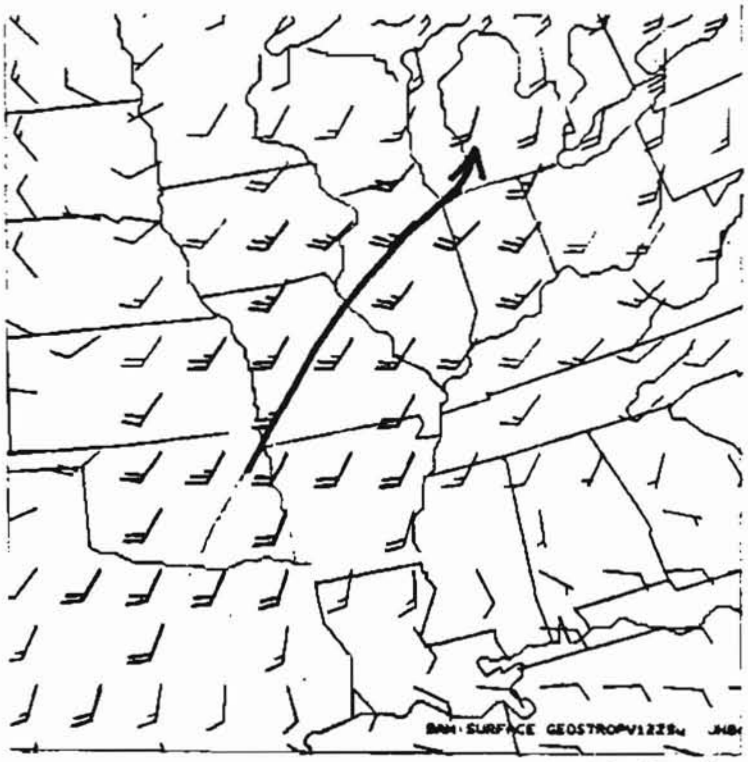


Fig. 25. 12 GMT surface geostrophic wind chart for 17 June 1984 with LLJ axis analyzed.

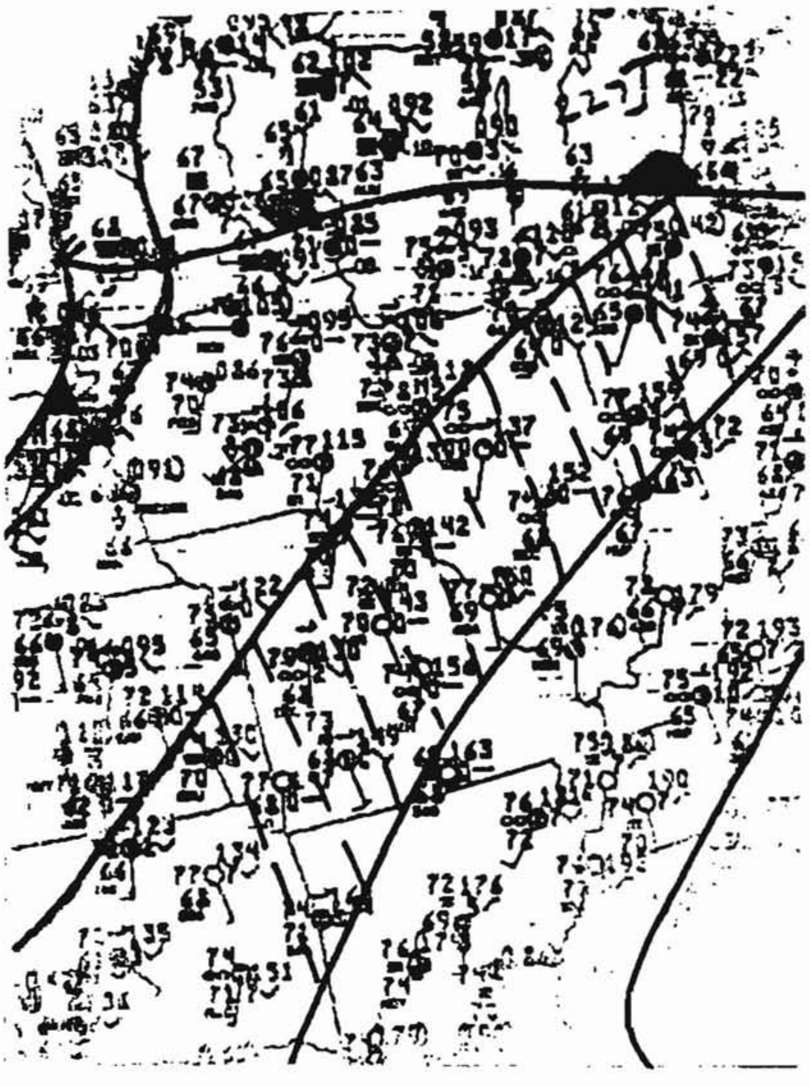


Fig. 26. Surface analysis, fronts, and isobars at 12 GMT on 17 June 1984. Hatched area is the general area where one should expect MDCZ development.

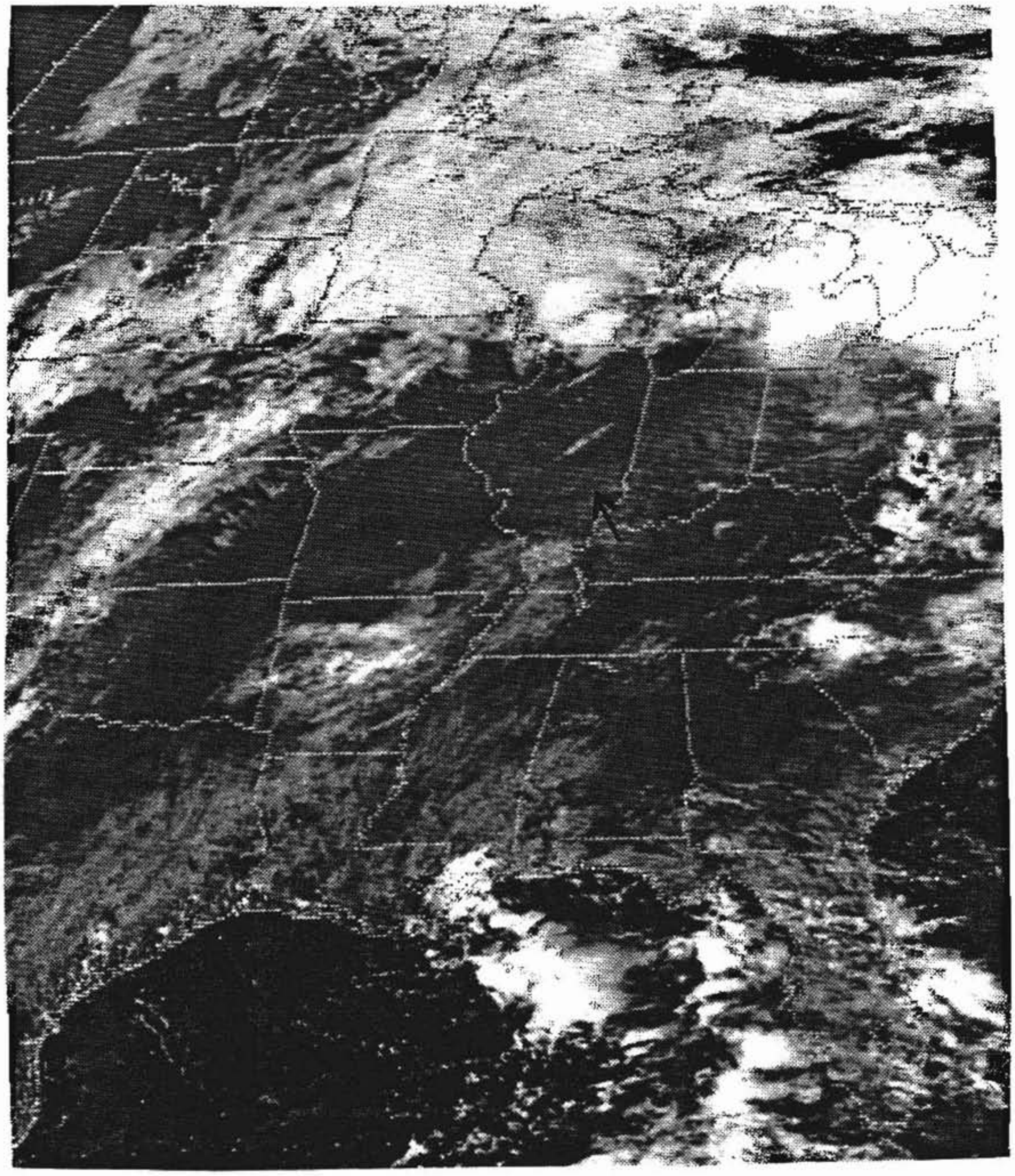


Fig. 27. 1430 GMT GOES picture for 17 June 1984. The arrow indicates cumulus cloud street over Central Illinois.

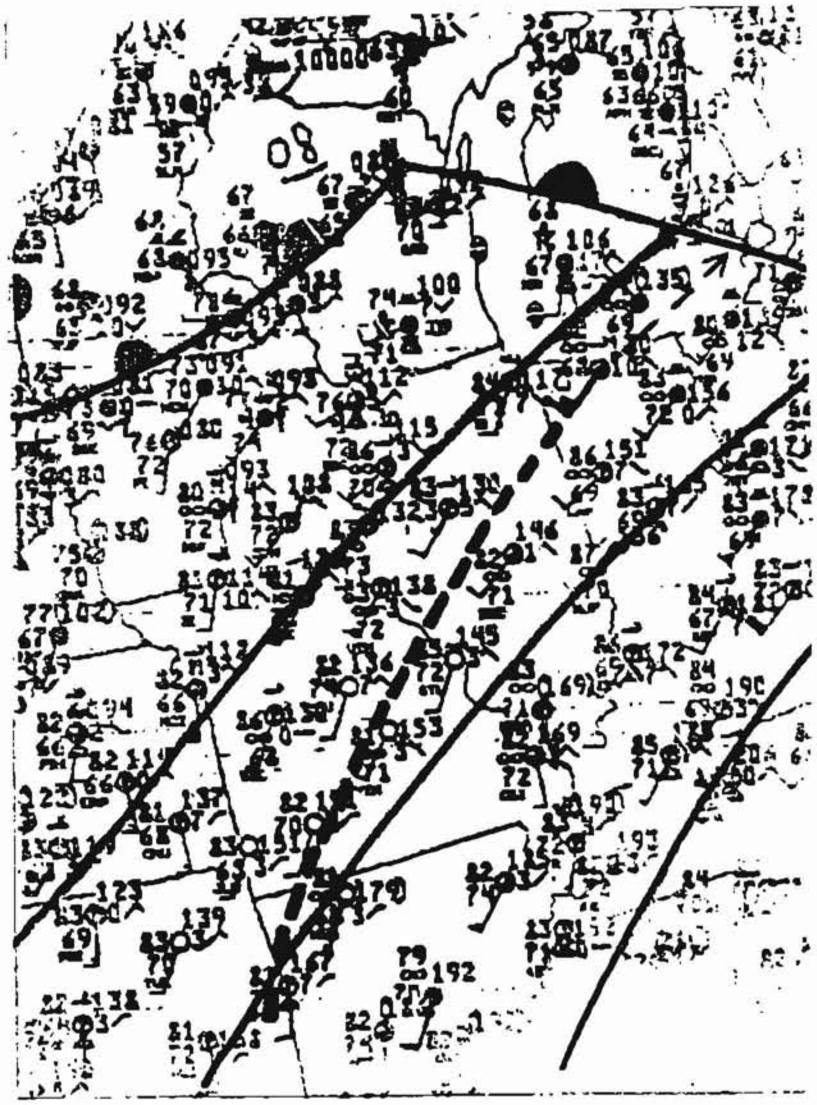


Fig. 28. 15 GMT surface analysis. The dashed line is a subjective forecast of where the LLJ axis will be during the afternoon.

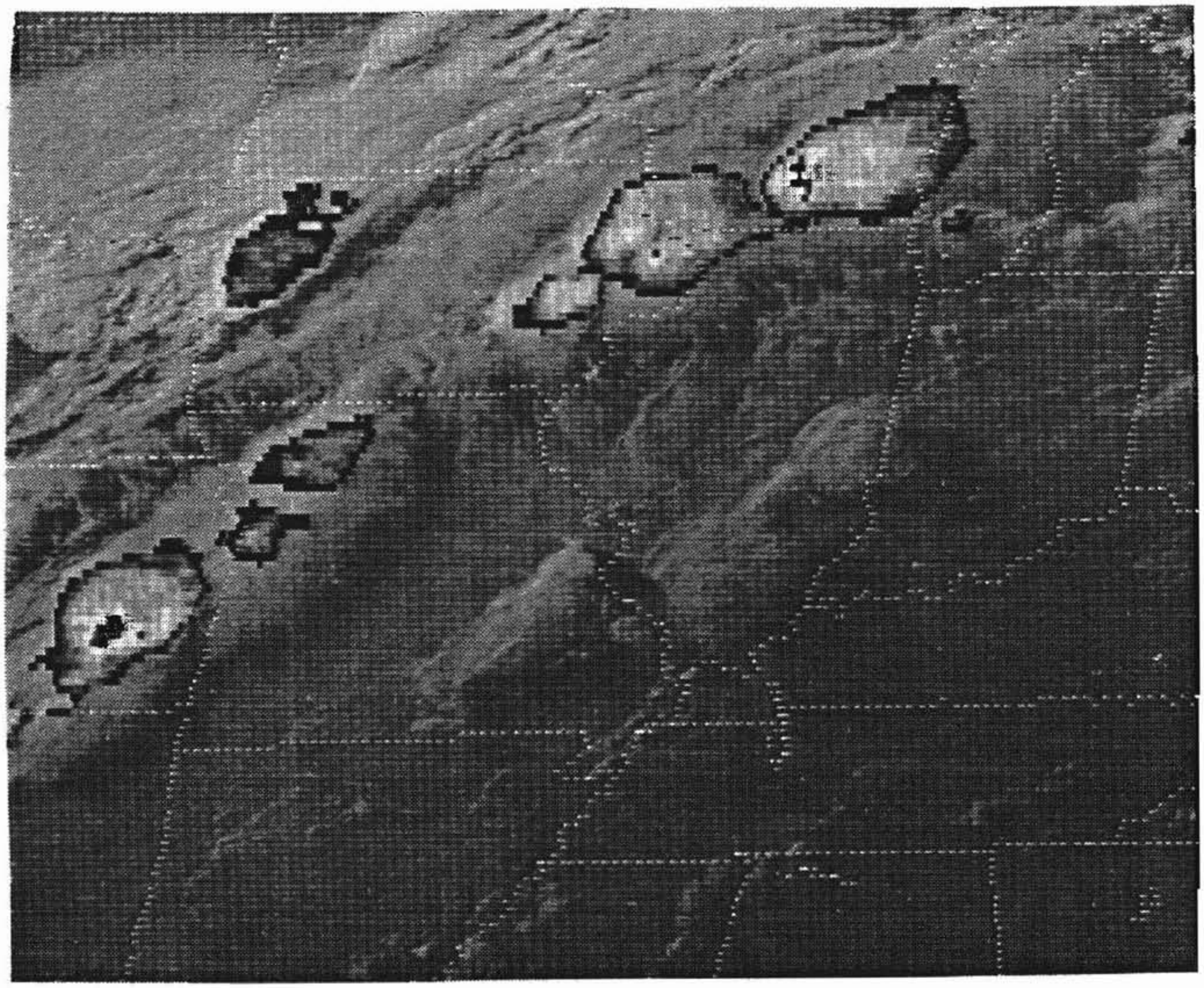


Fig. 29. Remains of the MDCZ at 0100 GMT on 18 June 1984

release time at least one will have a good indication of where afternoon thunderstorms will be concentrated, and the forecast can always be updated. Some success may also be possible using the LFM boundary layer wind forecast.

Because the wind field does not turn with height the squall lines produced will generally not show much movement perpendicular to the line and the individual thunderstorms will move along the squall line axis. As surface heating decreases the squall lines will begin to dissipate rapidly due to the diurnal oscillation of the frictional forcing mechanism. It is interesting to note that on 17 June and 10 July isolated thunderstorms in the MDCZ briefly increased in intensity when surrounding convection was dissipating, but in general thunderstorms were over by 0000 GMT or 6 PM CST. Fig. 29 shows the last vestiges of MDCZ convection slowly dissipating from southeastern Missouri to central Ohio, while strong thunderstorms are intensifying near the frontal zone.

Fig. 29 also raises an important point and puts the MDCZ into perspective. On the days of the MDCZ forecasters in the area are often concerned, and rightly so, about nocturnal severe weather moving with, or out ahead of, the frontal zones. This may well be the reason that the effects of the daytime LLJ have gone largely unnoticed; however, the case studies presented indicate that afternoon severe thunderstorms and even weak tornadoes are possible along the MDCZ. These are not random air mass thunderstorms, but are organized and associated with much stronger dynamics than may have been previously considered. Overshooting thunderstorm tops at the north end of the MDCZ were evident on the satellite images of all four cases presented in this paper. The northern end of the MDCZ should be closely monitored during the afternoon, especially if low level moisture is very high and stability indices are very low.

5. CONCLUDING REMARKS

The findings of this paper are of a preliminary nature. My main thrust has been to provide examples of the MDCZ and to somewhat avoid addressing the complex physical and dynamical processes that must be involved in its formation. The LLJ is always considered in a thunderstorm forecast because it is one of many important contributing factors to the dynamics of severe weather. One can't easily determine which particular factor is most important to a severe weather episode, or isolate the effects of the various contributing factors, but is is felt that in the MDCZ we are seeing the LLJ acting in isolation. In essence, we see what the LLJ can do by itself, and the results are impressive under certain conditions. Of course, the LLJ can probably only produce strong thunderstorms in a moist, unstable atmosphere, and that's why the MDCZ is strictly a summer phenomenon. The LLJ is so often present and associated with thunderstorms that one must be careful to keep the MDCZ in the proper context. It's interesting and yet somehow intuitively obvious that the MDCZ should reveal itself under summer anticyclonic conditions and weak synoptic influence. In hot, humid, and unstable anticyclonic weather one tends to expect random thunderstorm development, yet more and more I believe that is not the case. At very low wind speeds local circulations and differential heating take on increased significance. As wind speeds increase we should intuitively expect a higher degree of order or organization to convection. On the days of the MDCZ synoptic influences are weak except for one: the presence of the low level jet.

6. REFERENCES

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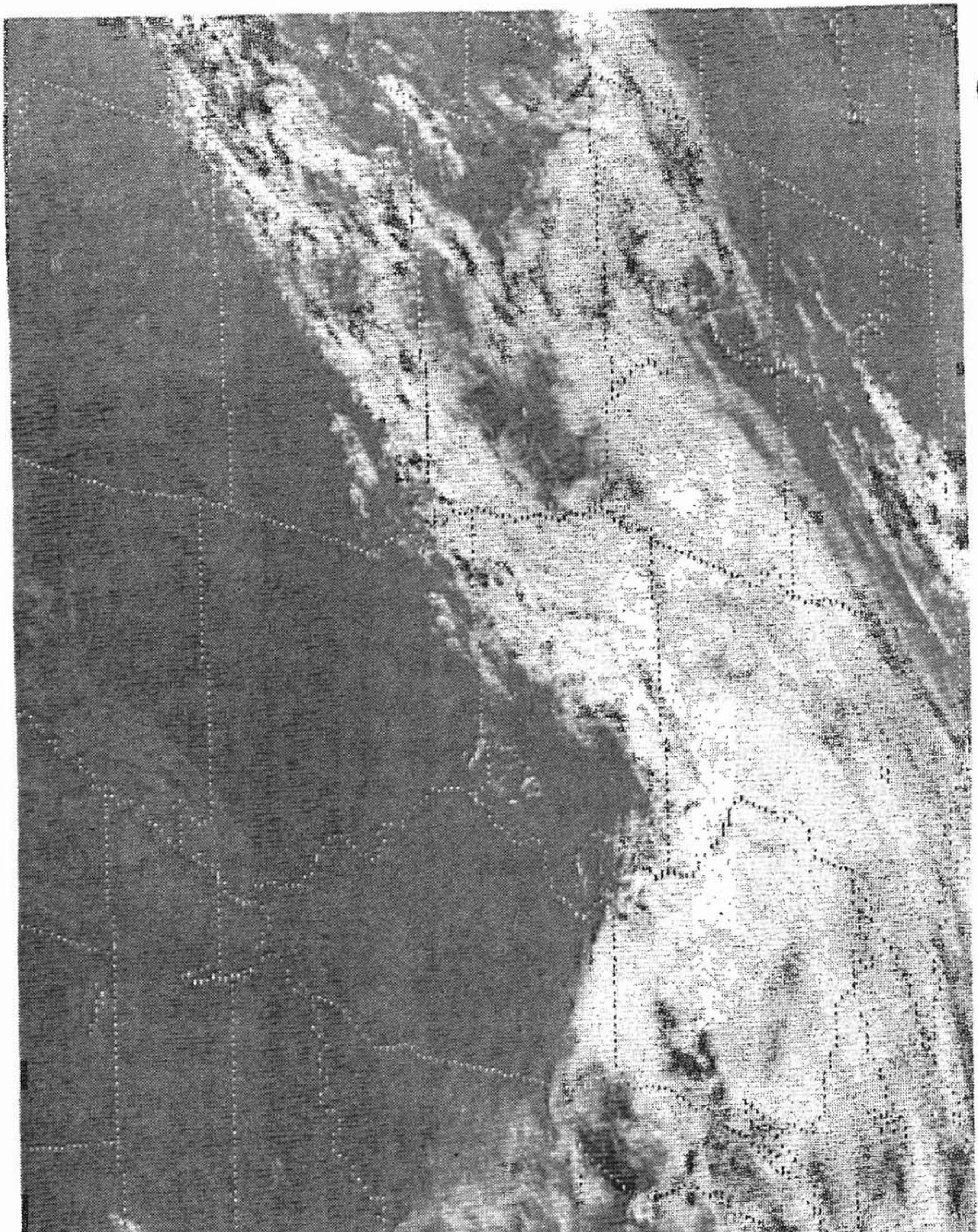
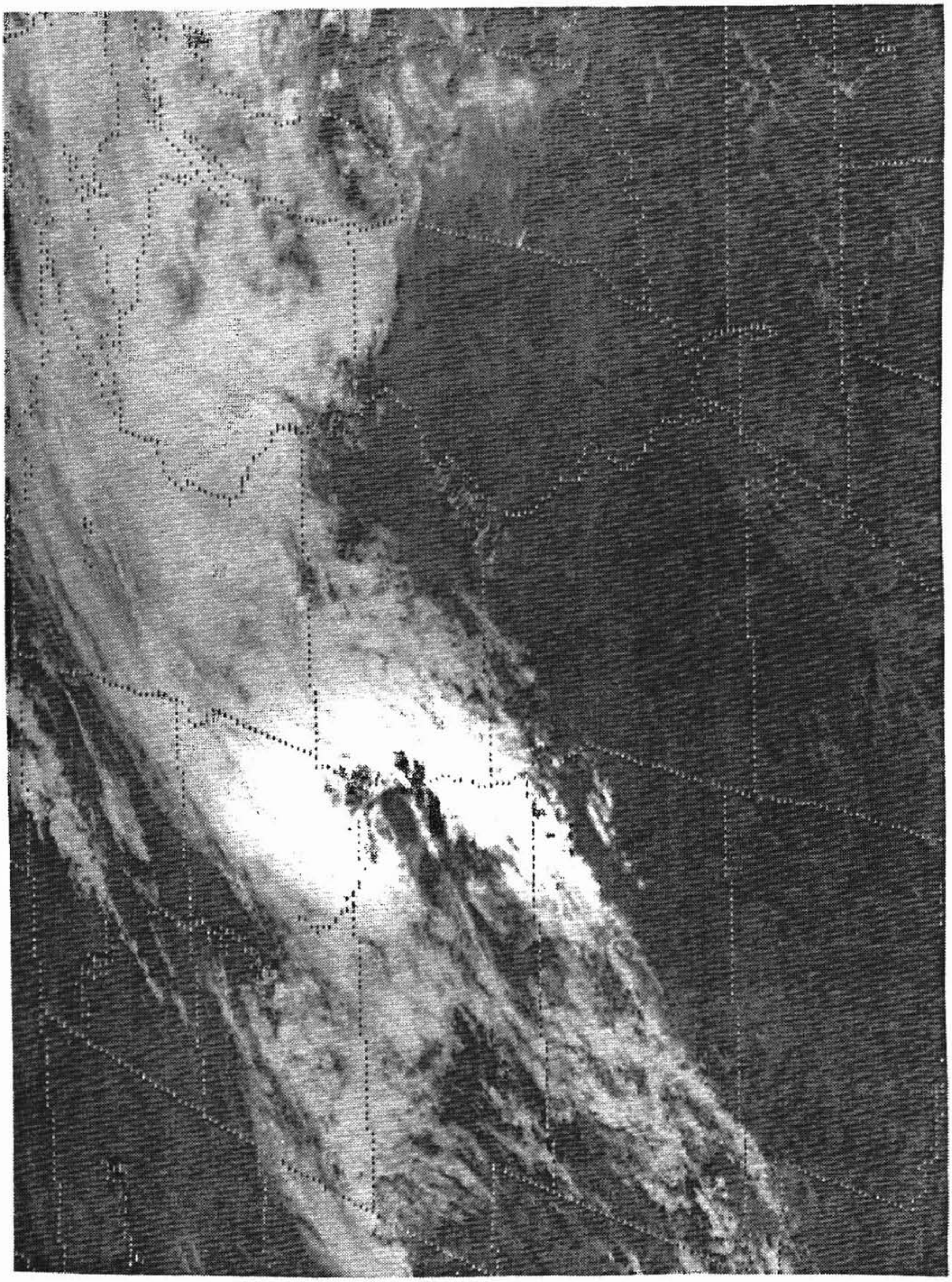
APPENDIX

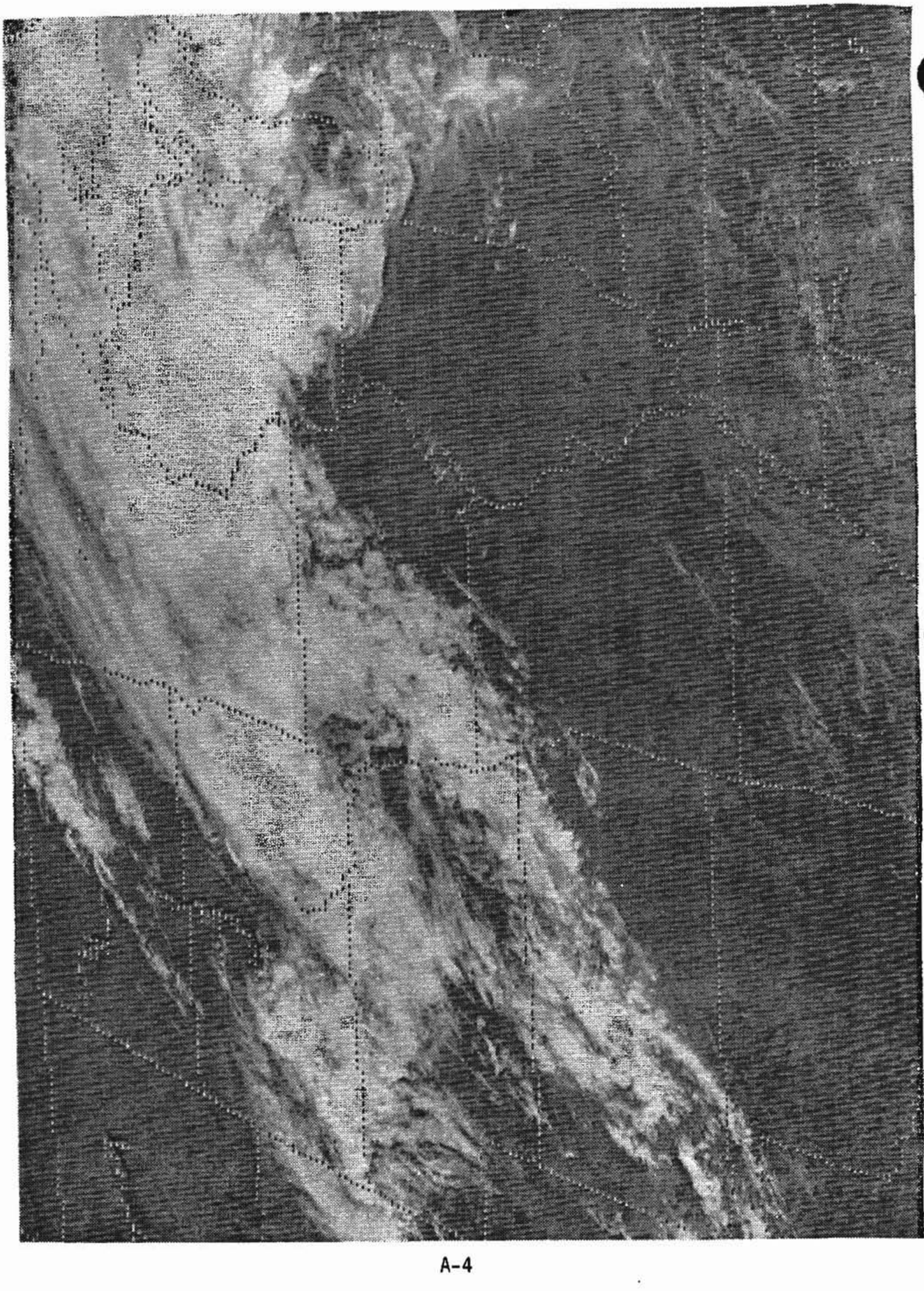
I have included a complete set of high resolution GOES pictures for 10 July 1984 which clearly show the diurnal course of the MDCZ from clear skies. I'll let the pictures speak for themselves.



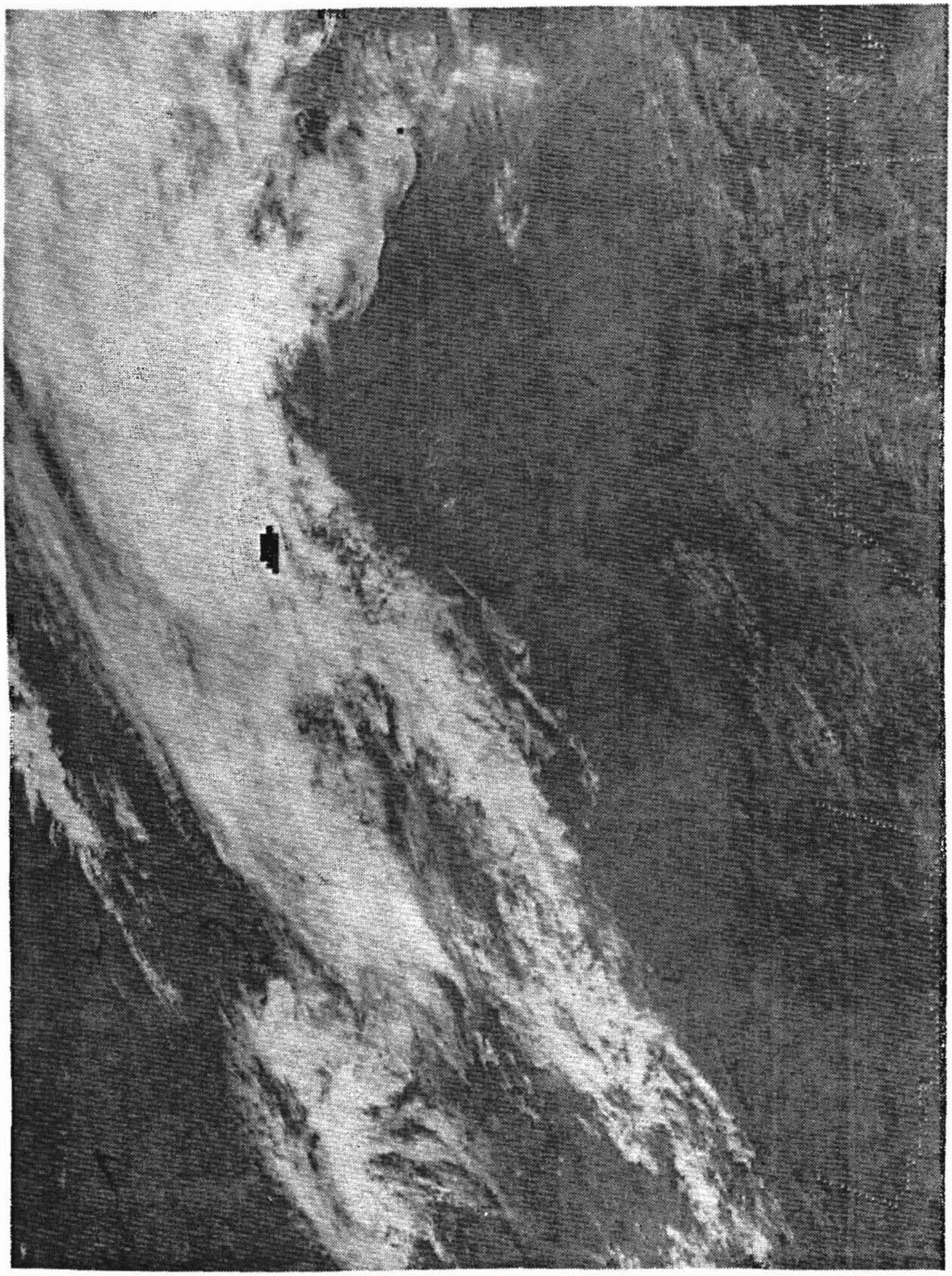
1501 GMT 1[illegible]ly 1984



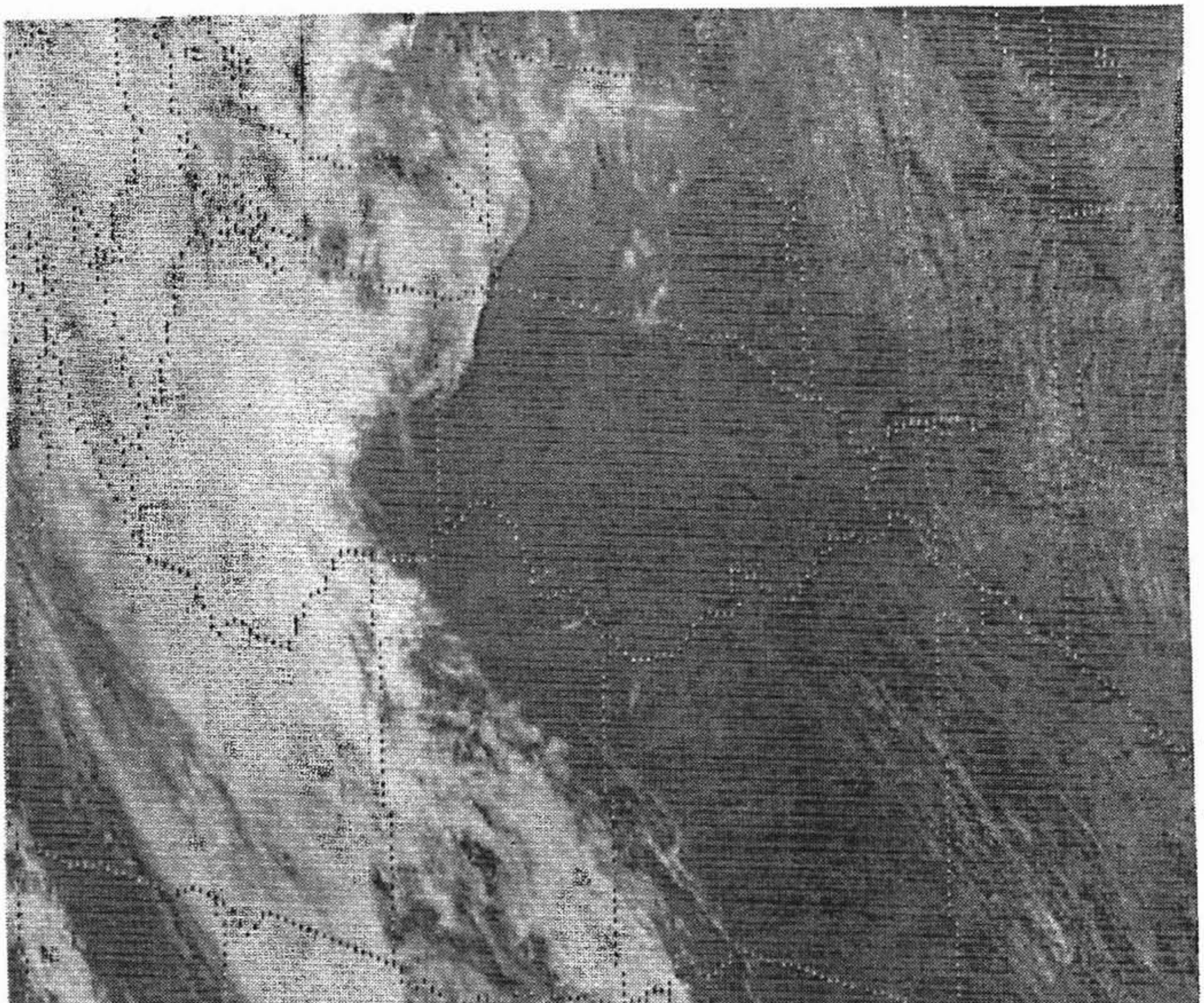
1531 GMT 10 July 1984



1601 GMT 1[illegible]ly 1984



1631 GMT 10 July 1984



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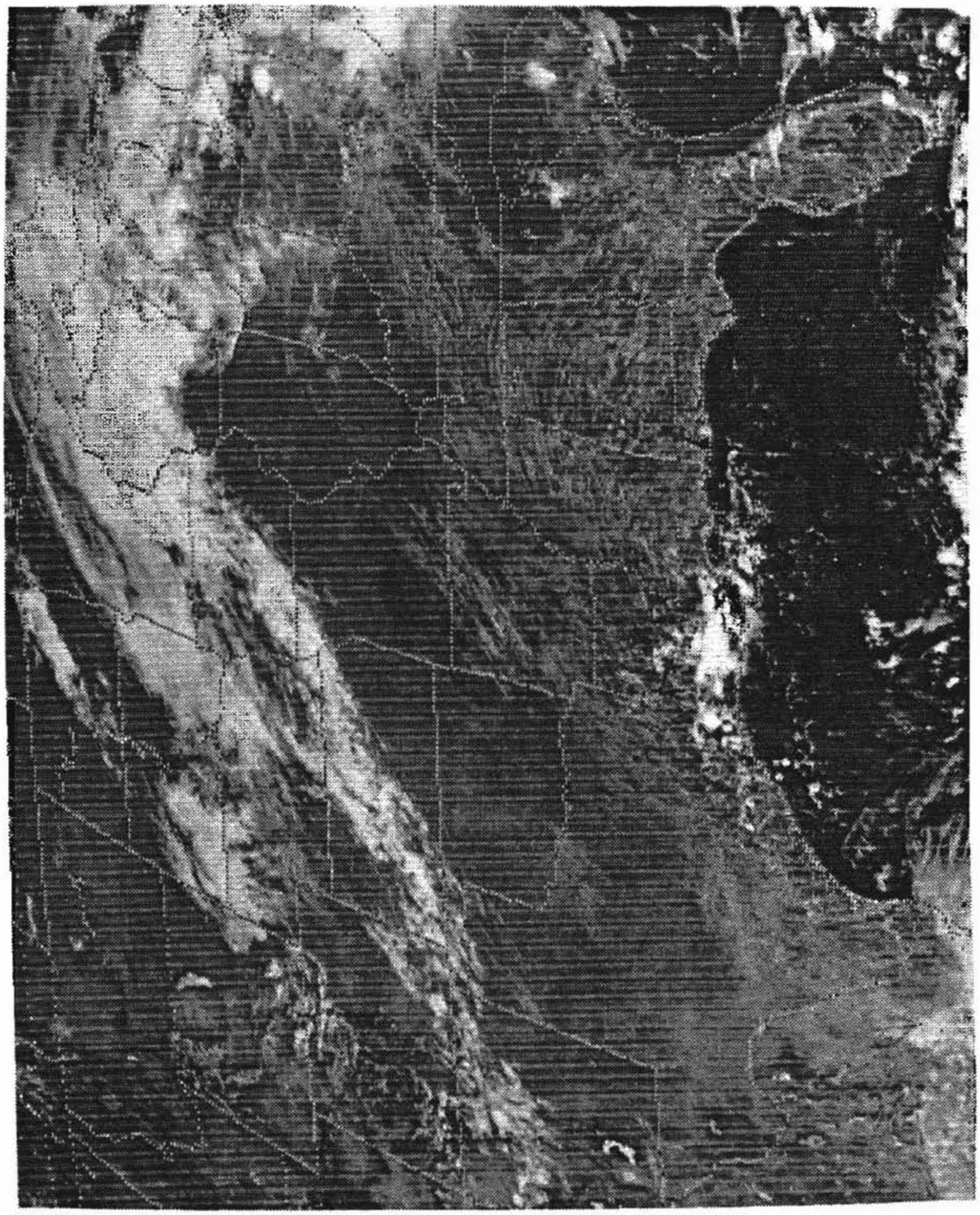

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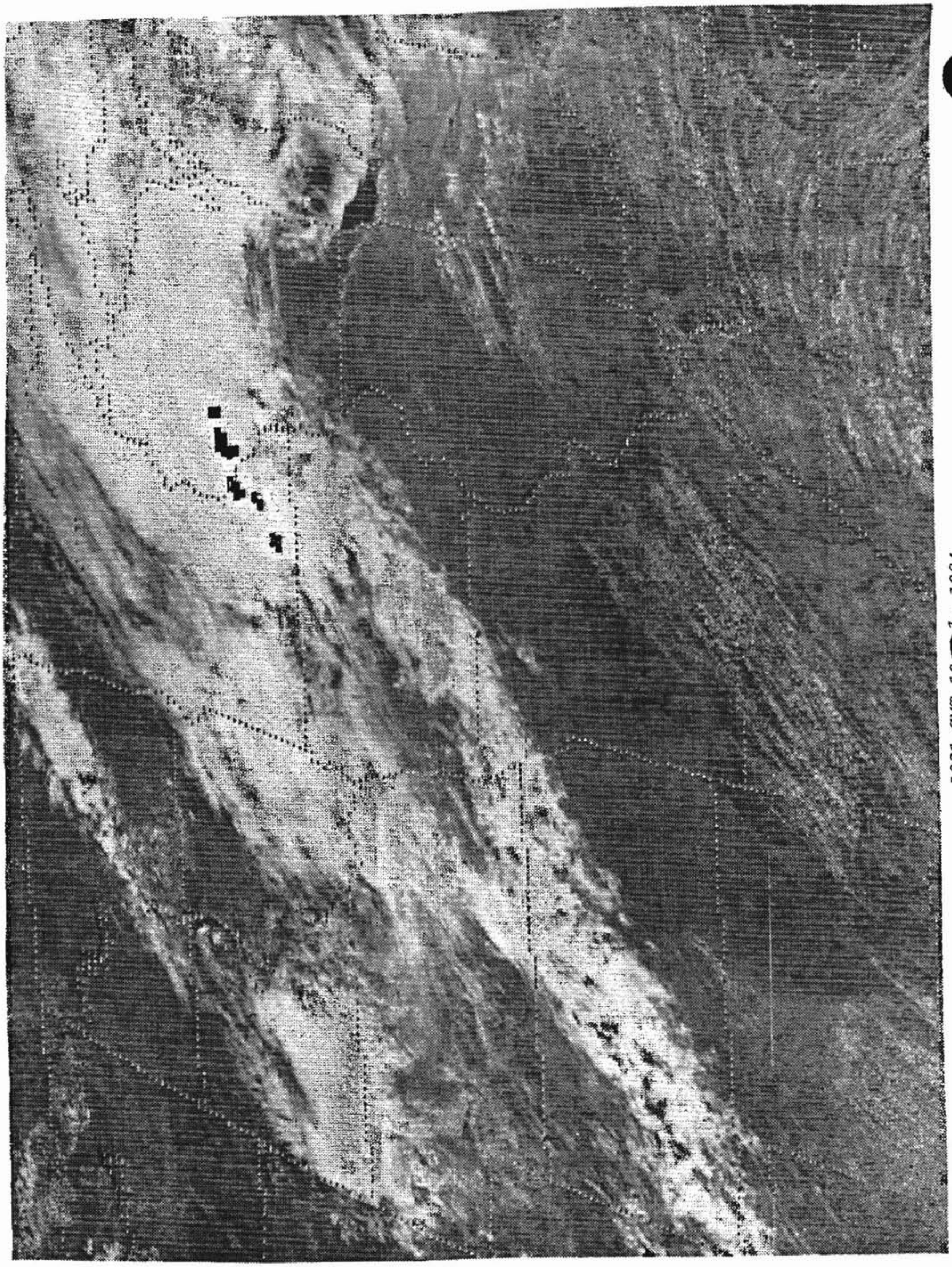
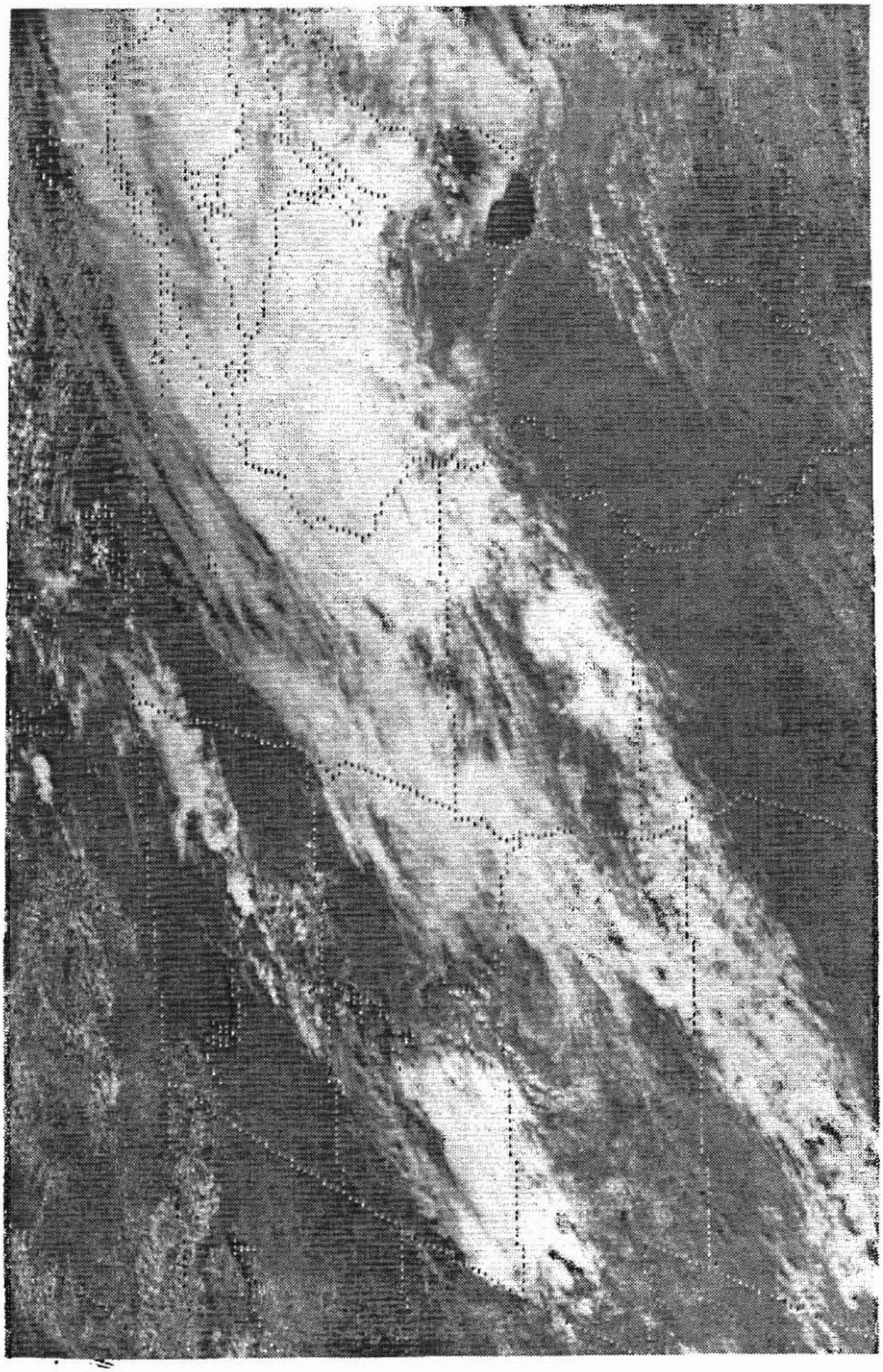


1831 GMT 10 ly 1984



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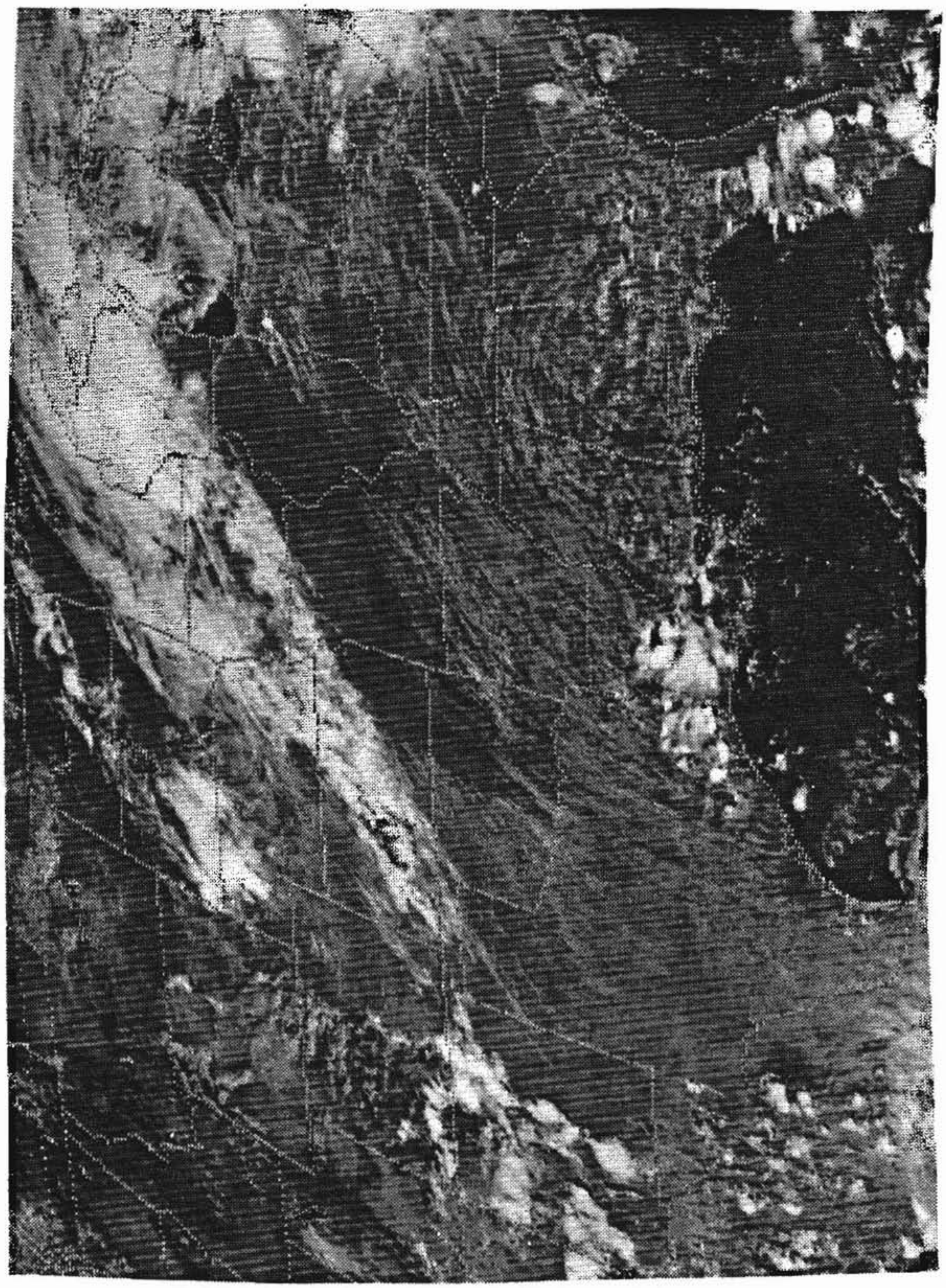
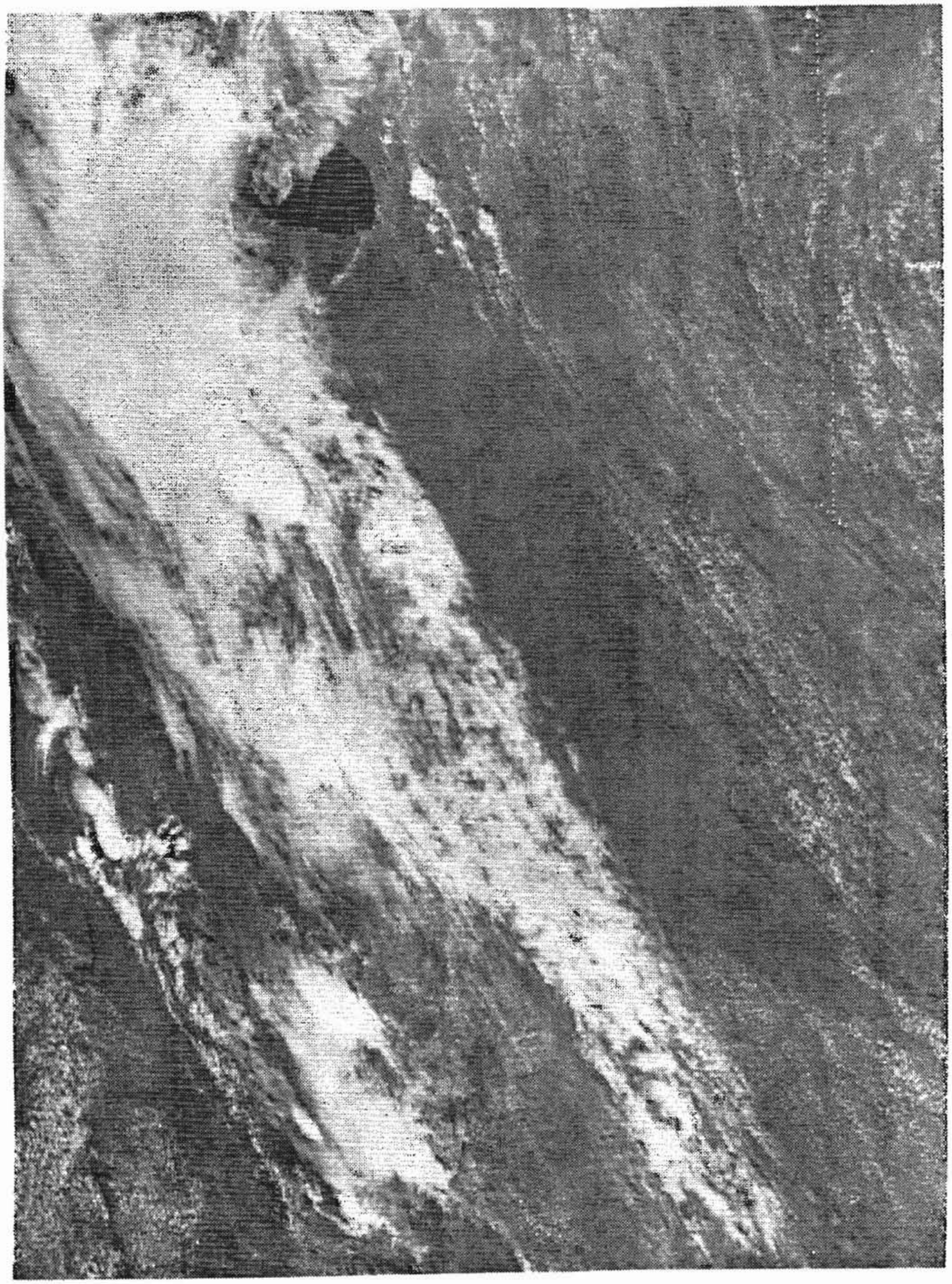
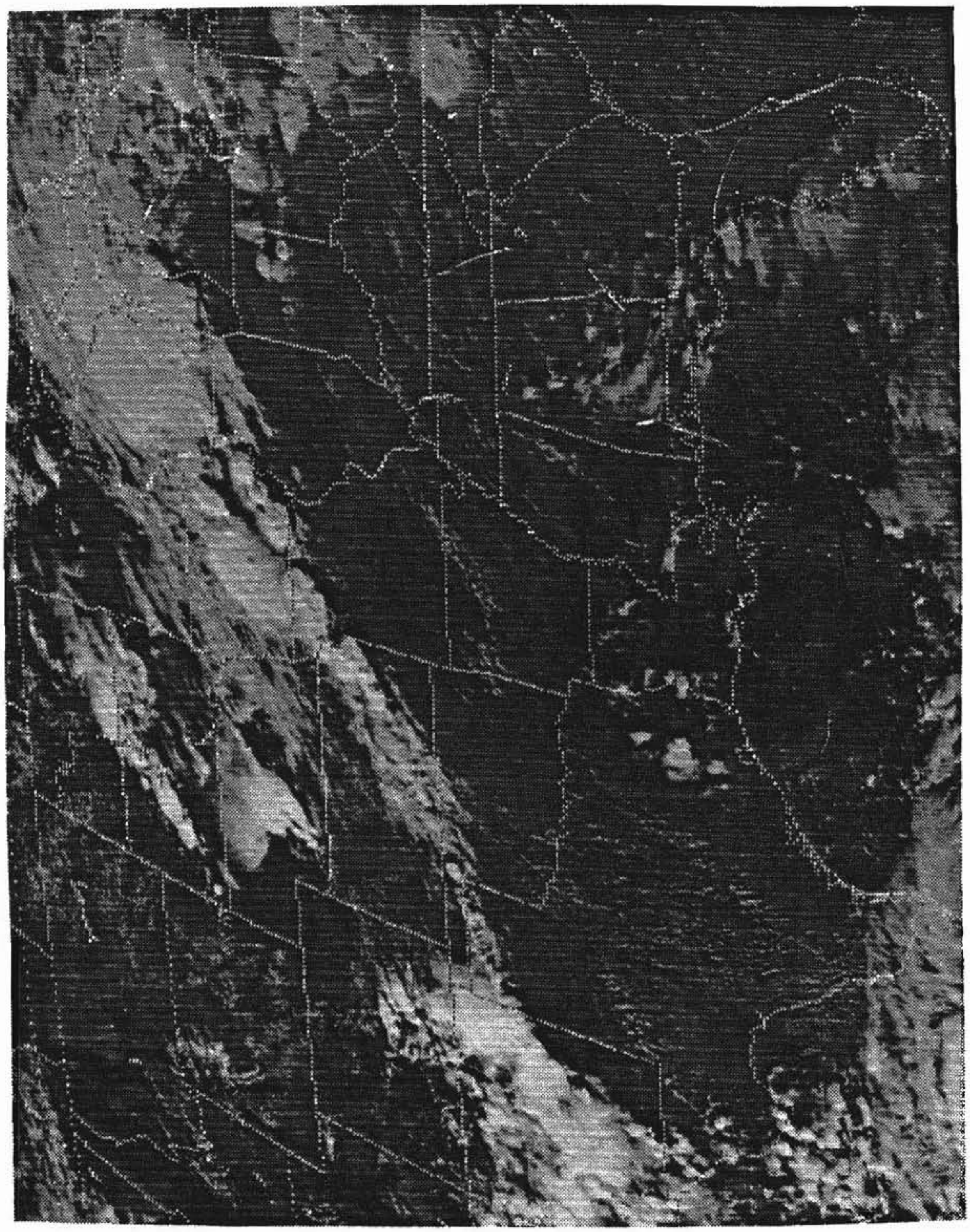


1931 GMT 10 July 1984



2001 GMT 10 July 1984

2031 GMT 10 [illegible]y 1984



2331 GMT 10 July 1984

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